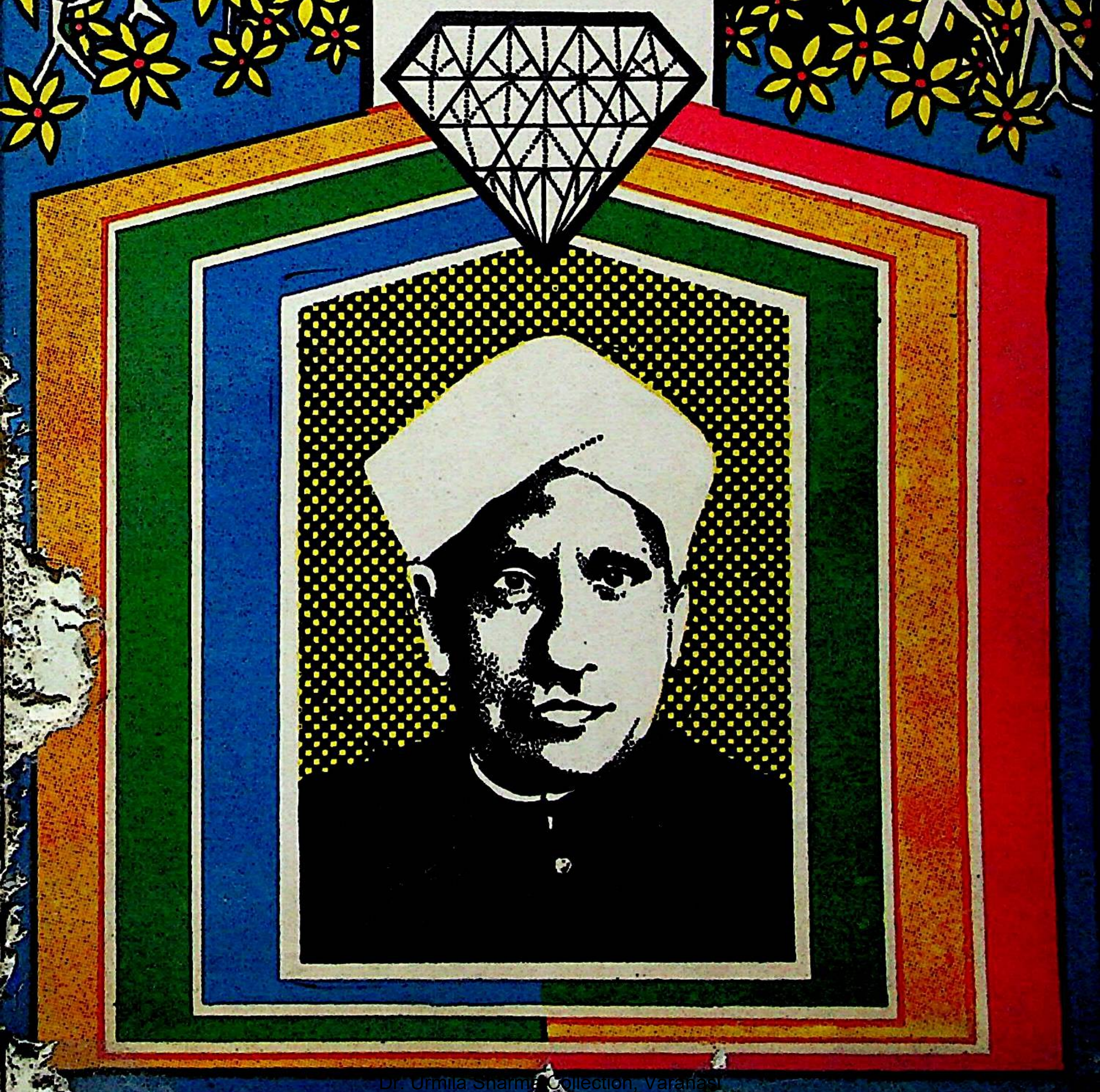
प्रज्ञा

काशी हिन्दू विश्वविद्यालय पत्रिका

अंक 33 भाग 2 - 34 भाग 1
वर्ष 1987 - 88

सर सी.वी. रमन
स्मृति अंक



नियम

1. 'प्रज्ञा', जहाँ तक संभव होगा, वर्ष में दो वार प्रकाशित होगी : प्रथम अंक दीपावली के तुरन्त बाद और दूसरा अंक होली के पूर्व ।
2. सभी प्रकार का शुल्क संपादक 'प्रज्ञा' काशी हिन्दू विश्वविद्यालय पत्रिका, वाराणसी - 221005 के नाम भेजें ।
3. पत्रिका में प्रकाशनार्थ काशी हिन्दू विश्वविद्यालय के छात्रों एवं अध्यापकों के लेख प्रथम अंक के लिए 20 जुलाई तक और द्वितीय अंक के लिए 20 नवम्बर तक संपादक-मंडल के पास पहुँच जाना चाहिए ।
4. लेख फुलस्केप साइज पर एक तरफ अंकित होना चाहिए और सामान्यतः 10 पृष्ठों से अधिक नहीं होना चाहिए। लेखकों को उनके लेख के प्रतिमुद्रण की 25 प्रतियाँ दी जायेंगी ।

1. The 'Prajna,' shall so far as possible, be published twice a year : one issue immediately after the Dipawali, the other immediately before the Holi.
2. All subscriptions should be sent to the Editor, ' Prajna". B. H. U. Journal, Varanasi-221005.
3. Articles intended for publication in this Journal by B. H. U. scholars should be submitted to the Editorial Board before July 20 for the first issue and November 20 for the next issue.
4. Ariticles should ordinarily be type-written on foolscap paper on one side only and should not ordinarily cover more than 10 pages. Authors contributing original articles to the Journal are entitled to receive 25 off-prints.

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प्रज्ञा

सर सी० वी० रमन स्मृति अंक

विद्ययाऽमृतमश्नुते
काशी हिन्दू विश्वविद्यालय
BANARAS HINDU UNIVERSITY

काशी हिन्दू विश्वविद्यालय पत्रिका
अंक 33 (भाग 2) एवं 34 (भाग 1)
वर्ष 1987-88

सम्पादक मण्डल 'प्रज्ञा'

डॉ॰ देवेन्द्र कुमार राय (प्रधान सम्पादक)

डॉ॰ हरि वल्लभ नेमा

डॉ॰ शिवप्रसाद सिंह

डॉ॰ जी॰ वी॰ मोहन तम्पी

डॉ॰ उषा किरण मेहरा

डॉ॰ हरिश्चन्द्र श्रीवास्तव

डॉ॰ अवरार अहमद

डॉ॰ रवीन्द्र नाथ मिश्र

सम्पादक

डॉ॰ राम मोहन पाण्डेय

आवरण सज्जा

हीरालाल प्रजापति

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सीमा प्रेस

ईश्वरगंगी, वाराणसी

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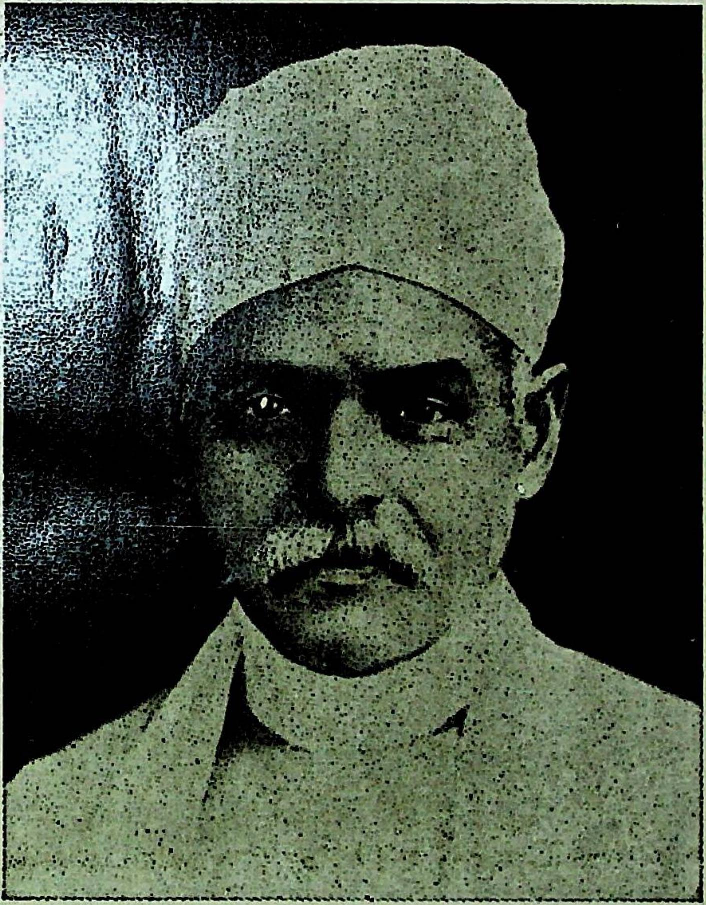
महामना पं० मदन मोहन मालवीय



न त्वहं कामये राज्यं न स्वर्गं नापुनर्भवम्।
कामये दुःखतप्तानां प्राणिनामार्तिनाशनम् ॥

आविर्भाव: वि० सं० १९१८ पौष कृष्ण ८ (२५-१२-१८६१)
तिरोधान: वि० सं० २००३ मार्गशीर्ष कृष्ण ४ (१२-११-१९४६)

कुलपति
VICE-CHANCELLOR

काशी हिन्दू विश्वविद्यालय
वाराणसी–२२१००५
Banaras Hindu University
Varanasi–221005

October 28, 1988:

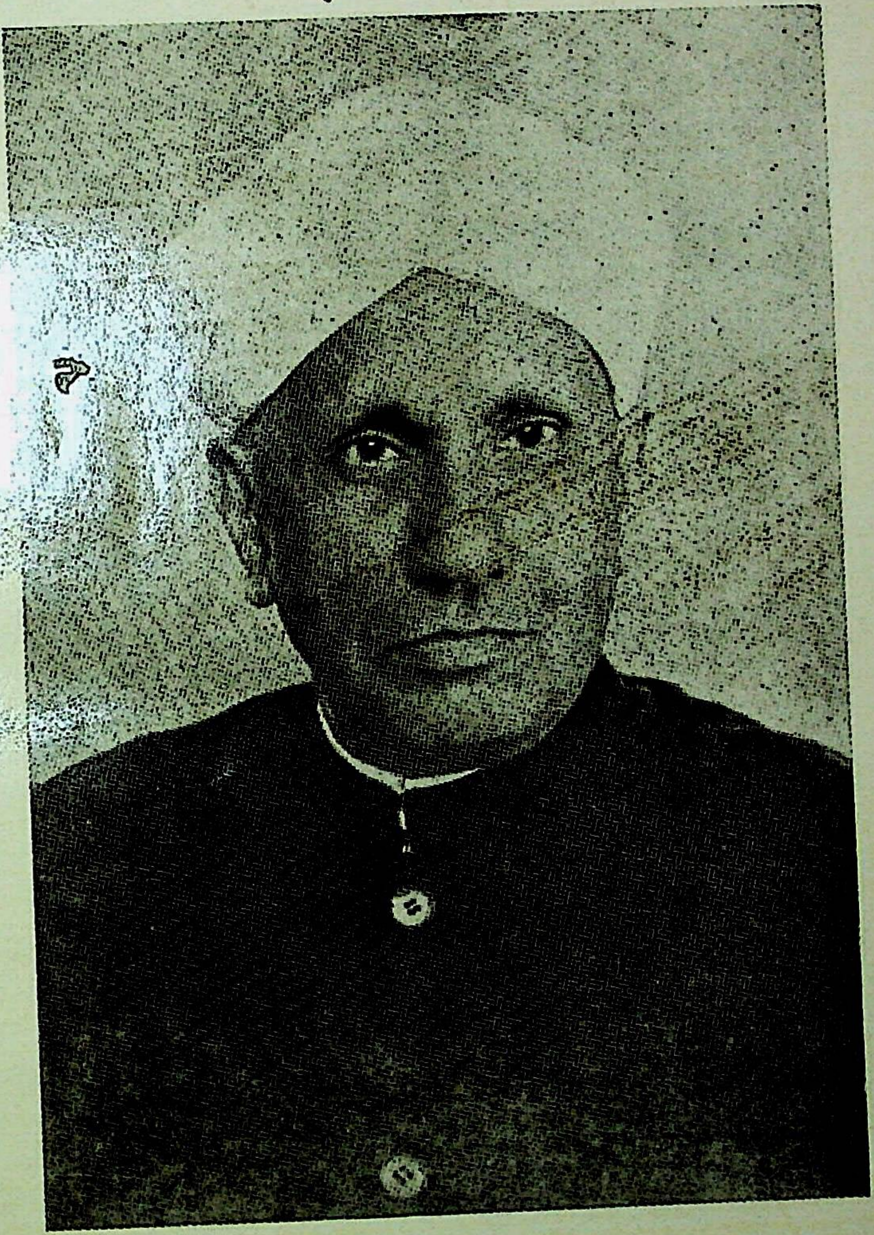
Professor Sir C. V. Raman was a great illustrious son of India. He was born during the latter half of the Nineteenth century a period which is somewhat unique in that it produced stalwarts in almost every field of human endeavour. For India it was a specially fruitful period since men of the caliber of Pt. Madan Mohan Malviya, Mahatma Gandhi, Gurudev Rabindra Nath Tagore, Pt. Jawahar Lal Nehru, Dr. S. Radhakrishnan, S. Ramanujam and a score of such illustrious personalities were born during these fifty years.

Professor Raman was a scientist who cannot be classed into the usual classes of Physicists, Chemists, Biologists. For him the whole of Nature was a field of investigation as his vast published work shows. It is interesting to note that Professor Sir J. C. Bose diverted his attention to the study of living organisms e. g. plants after he noted the 'tiredness' felt by his inanimate microwave detectors. Professor Raman has had a lifelong interest in colour and it was therefore natural for him to tackle the problem of vision as after all the perception of colour is intimately associated with vision. His deep knowledge and interest in musical instruments was noted quite early and he gained international recognition at first through that work. His studies of light scattering which led to the well known Raman Effect form a glorious chapter in Indian Science.

Raman was a great nationalist. He wanted India to gain a status in International Science worthy of its glorious past. He was therefore, greatly perturbed and pained by what he saw as "Camp following" of the west by scientists in India. He stressed the need of a sharp mind and hard work as the basic requirements of good science rather than expensive equipment and beautiful laboratories. His is a shining example in this respect. which needs to be emulated.

Professor Raman had a very charming personality. He could keep the audience spell–bound even during his scientific lectures. He had great affection for our university and cherished throughout his life his association with Mahamana Malviyaji. He was associated with the BHU family as an Honorary Professor. We accordingly decided to celebrate his birth centenary in a suitable manner. This special issue of our University Journal Prajna is an effort in this direction. There are articles by Professor Raman's students and contemporaries which bring out the various facets of the personality of Professor Raman. It is hoped that this issue will succeed in giving to our young students and faculty an idea about him. I wish to express my thanks to the authors of the various articles for their contributions and my appreciation to the Editorial staff for bringing out the issue on time.

R. P. Rastogi
Vice-Chancellor



Sir C. V. RAMAN
1888–1970

PREFACE

Professor Sir C. V. Raman was one of the most illustrious sons of India. He had already acquired a measure of an All-India reputation by the year 1916 when the foundation stone of this great National University was laid through the efforts of another of Mother India's illustrious sons, Mahamana Pandit Madan Mohan Malviya. It was therefore, but natural that a close association should be formed not only between the two men but also between Professor Raman and the Banaras Hindu University. It is therefore, not surprising that Raman was one of the distinguished speakers who gave public lectures in the evening during the week long Foundation day ceremonies in 1916. The topic of his talk was Ancient Indian Mathematics. As one would notice from the bibliography of Raman's work included in this issue, these were the days when he was engaged in the study of musical instruments and their tones. He was especially intrigued by the capacity of the mridangam and the tabla to give musical sounds whereas their close western counterparts the drums only produced noise. Similarly noteworthy to Raman was the capacity of Veena to mimic human voice. All this must have generated a great interest in the Ancient learning of this country and the choice of Raman's talk topic was a part of this interest.

Raman was for many years a Honorary Professor of this University—a fact which he mentions in the Convocation Address (reprinted in this issue) which he delivered in 1929. It may seem surprising to many that Raman gave this address extempore. Many stories about his mannerisms and orational skills are still prevalent among the older (now retired or retiring) teachers of this university. A visit of Professor Raman to this University in 1948 was recalled by Professor B. M. Shukla, former professor of Chemistry (he was then a student and resident of Broacha Hostel in the University). Raman's 60th birthday was being celebrated with a typical south Indian (rasam, sambhar, rice) meal on the spacious roof of the

Hostel. Raman joked and asked the students to investigate why delicious smells and taste of food are related. This is a question which still awaits elucidation.

I was not fortunate enough to have seen or heard Raman in person (though he lived upto 1970, and in fact some of my classmates had a chance to see him in 1963 in Madras, where Professor G. N. Ramachandran had organized an International Meeting on Crystal Structure) but I had heard so much about his many qualities that I have made a mental picture of him. When we visited the Raman Research Institute in Jan. 1971, just a couple of months after his death we had the good fortune of meeting with Lady Raman. When she was told that we are from the Banaras Hindu University, she recalled their association with this University and told us about how Professor Raman felt sad when he heard something uncomplimentary about Malviyaji's University.

In view of the close association of Professor Raman with our University, it was decided by the Editorial Board of the University Journal Prajna, that a special commemorative issue be brought out at the time of his birth centenary. Our Vice-Chancellor Professor R. P. Rastogi supported this idea enthusiastically and readily agreed to be the Chairman of the Special Editorial Board for this issue. He also wrote personal letters to eminent scientists in our country seeking their suggestions. A National Advisory Commitee was constituted. We tried to contact, students of Professor Raman, many of whom are still active and obtained letters of support and promises of articles (some of which could not be fulfilled due to pressure of other work). I found a very good collection of tributes in the Memorial Issue published by Current Science in May 1971 and got permission to use some of this material. Three historical articles were printed in the Proceedings of the Sixth International Conference on Raman Spectroscopy held at Bangalore in 1978 (on the fiftieth anniversary of the discovery of the Raman effect) and the authors and the publishers were gracious to grant permission to publish excerpts from the same. Similarly an article published in Physics Today May 1986 was felt appropriate as it gave some idea of the social and intellectual millieu in Pre-independence India as related to scientific activity. Again the author and the publisher agreed to our request for permission to reprint this article.

Professor S. Ramaseshan, Professor R. S. Krishnan, Dr. A. Jayaraman, Professor D. D. Pant and Professor P. R. Pisharoty-all former associates of Professor Raman, contributed very interesting material for inclusion in this issue. Professor N. Bloembergen despite his busy schedule of visits sent an inspiring message and Professor G. Herzberg who is in his late eighties sent a moving article. Professor George Series, wrote an illuminating short article bringing out the close similarities between optical pumping and Raman scattering. Two senior scientists Professor N. L. Singh and Professor D. Sharma wrote about their own impressions in Hindi. My colleague Professor S. N. Thakur has summarized the recent techniques in Raman spectroscopy and their applications. An eulogy in Sanskrit verse has been provided by Pandit Shiva Dutt Chaturvedi, and an interesting arlicle by Pandit Janardan Upadhyay relates Raman Effect and Surya Vijnan.

I am greatly indebted to all these persons for having spared so much of their valuable time to prepare these articles for this special issue. I am conscious of my own limitations which have played a large part in preventing this special issue from being much more valuable than what it is–but I pray and hope the readers will forgive me. I have derived great pleasure and inspiration in reading through the material–even those that is not included for any reason—and I would feel amply rewarded if my dear students—for whom this collection is primarily intended—get a glimpse of the great personality of Professor Sir C. V. Raman.

—D. K. Rai.

Acknowledgements

We are grateful to the following persons and institutions for permission to reproduce published material in this Special issue. The original publication is indicated as a footnote on the first page of the article in most of the cases.

Professor S. Ramaseshan for the following Three articles;

(i) C. V. Raman—which is the text of the first Raman Memorial lecture delivered at the Indian Institute of Science, Bangalore in 1978.

(ii) C. V. Raman and the German Connection—which is adapted from an article of the same title published by Science Age in Feb. 1987.

(iii) Professor Raman on the Raman Research Institute which was published in Current Science—May 1971.

and for the inscription on the Malviya Commemoration Volume.

Dr. William A. Blanpied and the American Institute of Physics for the article entitled "Pioneer scientists in Pre-independence India" first published in Physics Today, May 1976.

The Manager, Current Science Association and the respective authors for the articles reproduced from the commemoration issue of the Current Science, May, 1971.

Professors S. Bhagawantam, D. A. Long and R. C. Lord and John Wiley & Sons, N. Y. for the articles of the above three authors which are adapted from the Proceedings of the Sixth International Conference on Raman Spectroscopy held at Bangalore, 1978.

We are grateful to Professor S. S. Banerjee and the Indian Association for the Cultivation of Science for the photographs of

Professor Sommerfeld's visit to the I. A. C. S. and of the farewell to Professor Raman on the occasion of the award of the Nobel Prize to him.

In addition I wish to record my special appreciation for the support and suggestions given by Professor R. P. Rastogi, Professor S. Ramaseshan, Professor D. D. Pant, Professor S. P. Pandya, Professor N. L. Singh and Dr. G. S. Rai in the task of bringing out this issue of Prajna. The general and technical support of Dr. Ram Mohan Pandey, Editor, Prajna has been invaluable during the whole process of publication.

To my dear and esteemed friend
Dr. Sir C. V. Raman
with deep affectionate regards.

M. M. Malaviya
10.2.32.

A commemoration volume was published by the Banaras Hindu University in 1932 to celebrate the 75th birthday of Mahamana Pandit Madan Mohan Malviyaji. Professor C. V. Raman contributed an article on "Raman Effect in Chemistry" for this volume. A copy of the commemoration volume was gifted to Professor Raman by Malviyaji with this inscription in his own handwriting.

'तुम्हं समान तुम्ह तात'

अध्यात्मोन्मुख भारतीय मनीषा अपरालोक की महत्ता के प्रति कभी उदासीन नहीं रही। प्रकृति की रहस्यमयी अनेकमुखी भंगिमा ऋषियों, मनीषियों, कवियों और वैज्ञानिकों के औत्सुक्य और सिसृक्षा को आकर्षित एवं उत्तेजित करती रही है। सहस्रों वर्ष पूर्व रचित ऋचाओं के प्रणेताओं की दृष्टि में भौतिक सौन्दर्य वोध उपेक्षित नहीं रहा, उसे अपेक्षित गुरुता देते हुए उन्होंने उसका रूपायन नाना रूपों में किया है, यद्यपि अदृश्य सत्ता के संधान में ही उनकी प्रतिभा क्रियाशील रही है। अपरा से फूटने वाली परा-द्युति को पकड़ने और उसे व्यवस्थित अभिव्यक्ति देने की प्रवृत्ति भारतीय वाङ्मय की सामान्य पहचान है। जिन्हें भारतीय विद्या परम्परा का प्रामाणिक परिचय नहीं है, वे बड़ी हीन शैली में यह कह दिया करते हैं कि धर्म-अध्यात्म के आत्यन्तिक आग्रह के चलते भारत में, भारतीय चिन्ता जगत में पदार्थ लोक का प्रायः निषेध है। अपेक्षित अभिज्ञता के अभाव में इस प्रकार की भ्रान्त धारणाओं का जन्म होता है, जो हमारी विरासत से वर्तमान को विच्छिन्न करने में अज्ञात रूप से सहायता पहुँचाती हैं।

आधुनिक युग के पराधीनता काल में भारत में ऐसे महापुरुषों का आविर्भाव हुआ जिन्होंने अपनी प्रज्ञा से न केवल भारतीय विद्या-परम्परा को जीवन्त-जाग्रत किया, बल्कि अपनी सारस्वत साधना एवं उपलब्धि से उसे विशिष्ट समृद्धि प्रदान करते हुए यह प्रमाणित किया कि भारतीय मनीषा की यात्रा कभी एकांगी और अतिवादी नहीं रही है। उसका उद्देश्य सदैव 'सुरसरि सम सब कहँ हित होई' का ही रहा है।

पदार्थ विज्ञान के क्षेत्र में साधनारत विद्याव्रतियों ने अपने विवेक से प्रमाणित किया कि पदार्थ विज्ञान अध्यात्म विद्या का विरोधी नहीं पूरक है। इतना ही नहीं विज्ञान का विधायक मूल्य क्षीण हो जाता है—यदि उसका उद्देश्य मनुष्य की संवेदना-समृद्धि न हो। मनुष्य को जड़ वस्तुओं का प्रामाणिक ज्ञान कराते हुए उसके मोह से विरत कर, उसे चिन्मय मूल्यों से जोड़ना ही विज्ञान या ज्ञान की किसी भी शाखा का चरम लक्ष्य है। आचार्य जगदीश चन्द्र बोस और सर सी० वी० रमन शीर्षस्थ भारतीय विज्ञान वेत्ता हैं, जो अपने महत् लक्ष्य को भली प्रकार समझते थे और जिन्होंने अपनी असाधारण प्रतिभा से विश्व के विज्ञान लोक को विशिष्ट समृद्धि दी।

आज हम जिस महापुरुष की पुण्य शताब्दि पर उनके विशिष्ट अवदान एवं अद्वितीय गुणों का स्मरण कर, उनकी गौरव-गाथा के पुण्य सलिल में स्नान कर अपने को बड़भागी

मानते हैं, उस महापुरुष–सर सी० वी० रमन का जीवन भारतीय आदर्श और चिन्तन का जीवन्त प्रतीक रहा है। भारतीय स्वाभिमान को विश्व में उन्नत करने वाले मनीषियों में प्रो० रमन का अप्रतिम स्थान है। उनकी उदग्र प्रतिभा का विकास पूर्णतः भारतीय परिवेश में ही सम्पन्न हुआ। वे ऐसे आदर्श भारतीय वैंज्ञानिक रहे हैं जिन्हें अपनी संस्कृति, सभ्यता, समृद्धि और ज्ञान पर गर्व रहा है। एक भारतीय आत्मा के रूप में प्रो० रमन ने जो ज्ञान-दीप प्रज्वलित किया उसकी ज्योति से सम्पूर्ण विश्व-चेतना आलोकित हुई और हम वैज्ञानिकों की अग्रिम पंक्ति में स्थान पा सके।

प्रो० रमन न केवल एक अद्वितीय वैज्ञानिक थे, अपितु साहित्य, संगीत और कला के भी उपासक थे, मर्मज्ञ थे। प्रकृति उनकी सहचरी थी, रंग-बिरंगे पुष्प उन्हें अत्यधिक प्रिय थे। उनके बहुमुखी व्यक्तित्व में अन्वेषण की तीव्र लालसा और साधना की असीम गहराई विद्यमान थी। सरलता, सादगी और सदाचारपूर्ण निर्भीक जीवन सरणि उनके भारतीयता की पहचान थी। प्रो० रमन एक महान तत्त्वदर्शी वैज्ञानिक के रूप में विश्व क्षितिज पर अमर हैं। उनका जीवन ज्ञान की अतृप्त प्यास से प्रारम्भ होकर विज्ञान के दर्शन में विलीन हो जाता है। यह भी एक मधुर संयोग है कि प्रो० रमन के शताब्दि वर्ष पर ही 'रमन प्रभाव' की हीरक जयन्ती मनाई जा रही है। 28 फरवरी 1928 विज्ञान जगत का वह अविस्मरणीय ऐतिहासिक दिन है जिसे प्रो० रमन की अद्वितीय खोज जन्य महत् उपलब्धि के चलते 'रमन प्रभाव' के रूप में स्मरण किया जाता है। इसी महनीय उपलब्धि को गौरव मंडित करते हुए 11 दिसम्बर 1930 को प्रो० चन्द्रशेखर वेंकट रमन को नोवल पुरस्कार से सम्मानित किया गया।

सम्प्रति मनुष्य जड़ वस्तुओं के प्रबल मोह में आवद्ध होता रहा है। न केवल सी० वी० रमन का देश भारत, वल्कि सम्पूर्ण विश्व भोगवादी प्रवृत्ति से ग्रसित और भोग उपकरणों के संग्रह में व्याकुल दृष्टिगोचर हो रहा है। अनन्त रचनात्मक ऊर्जा के अधिपति मनुष्य को आत्मनाश की यात्रा से कैसे विरत किया जाय, यही आज की सबसे बड़ी चुनौती है। ऐसे समय में विज्ञान दृष्टि की प्रासंगिक महत्ता बढ़ गयी है।

चिन्तकों को अध्यात्म का पथ अत्यन्त उपयुक्त प्रतीत हो रहा है। सी० वी० रमन सीमित अर्थ में अध्यात्म-पथ के पथिक नहीं थे, किन्तु उनकी साधना का चरम लक्ष्य मानव मांगल्य ही था। अध्यात्म की मूल प्रवृत्ति और उद्देश्य इससे भिन्न नहीं है। भौतिकता और अध्यात्मिकता की दूरी कम करने वाली दृष्टि ही विधायक होती है। प्रो० रमन की यही दिशा थी। भोग-संसक्त और अपने उद्धार की राह से अपरिचित आज के मनुष्य की दीन दशा को देखते डॉ० रमन के अवदान की महत्ता सहज ही स्पष्ट हो जाती है। सारा विश्व श्रद्धा और कृतज्ञता के साथ भारतीय विज्ञानवेत्ता प्रो० रमन को शताब्दि वर्ष के पुण्य पर्व पर स्मरण कर रहा है, जो एक संकेत है कि शुभ शक्ति के संधान की भूख अभी जीवित है। और जब तक यह अभीप्सा जाग्रत है मनुष्य के भविष्य की सुरक्षा जीवित है।

'प्रज्ञा' के विशेषांकों की परम्परा में प्रस्तुत 'रमन स्मृति अंक' विज्ञान की उस दिशा को रेखांकित करने के उद्देश्य से प्रकाशित किया जा रहा है जिसके अप्रतिम पुरस्कर्ता प्रो० सी० वी० रमन जैसे भारतीय मनीषी थे। देश पूज्य महामना पं० मदन मोहन मालवीय के जादुई व्यक्तित्व और स्नेह भरे आग्रह को कोई भी विद्यानुरागी टाल नहीं पाता था। प्रो० रमन के साथ भी ऐसा ही हुआ और एक वार जब सानिध्य-सम्पर्क वना तो आजीवन उसकी 'रमणीयता' यथावत बनी रही। महामना और उनके इस महान विद्या मंदिर के प्रति प्रो० रमन के मन में अगाध श्रद्धा विद्यमान थी।

सामान्य रूप से अपने आदरणीय पूर्वजों के प्रति श्रद्धाभिव्यक्ति हमारा पुनीत कर्तव्य है। पर यहाँ हमारा दायित्व और सघन हो गया है। हम संकुचित हैं कि उस विराट व्यक्तित्व की अर्चा के अनुरूप भव्य उपादान प्रस्तुत नहीं कर पा रहे हैं। पर, हमारी परंपरा भाव-प्रवणता को विशेष महत्व देने की रही है। किञ्चित पत्र-पुष्प ही भावना से जुड़कर जिस भक्ति का सृजन करते हैं हम वही पुष्पाञ्जलि लेकर संकोच सहित उस मनीषी के समक्ष नतशिर खड़े हैं। सम्पूर्ण विश्वविद्यालय परिवार की ओर से उस युग पुरुष, महान वैज्ञानिक का कोटिशः वन्दन—अभिनन्दन।

साहित्य का एक अदना विद्यार्थी होने के नाते प्रो० रमन के वारे में कुछ कहना या लिखना मेरी शक्ति सीमा से परे हैं। पर अपने प्रधान सम्पादक प्रो० डी० के० राय की इच्छा को आदेश मानकर मैंने दो शब्द लिखने का प्रयास किया है। आप इसे इसी रूप में स्वीकार करें, यह मेरा विनम्र अनुरोध है।

प्रस्तुत अंक की उद्‌भावना प्रो० राय के ही 'मानस' की उपलब्धि है। इस सम्पूर्ण योजना और उसकी क्रियान्विति के दायित्व का निर्वाह प्रो० राय ने जिस उत्साह, तन्मयता, कुशलता और श्रम से किया उसे नजदीक से देखकर एक वैज्ञानिक आदर्श के प्रति समर्पित व्यक्तित्व का किञ्चित बोध हुआ। मेरे लिए प्रो० रमन की उच्च साधना का रहस्य जानने में इससे इतनी सहायता मिली कि स्वतः ही मन श्रद्धा से भर उठा।

विद्यानुरागी अपने कुलपति प्रो० रघुनाथ प्रसाद जी रस्तोगी के समक्ष जब हम अपनी यह योजना लेकर उपस्थित हुए तो सहज ही उनका वरदहस्त हमें प्राप्त हो गया। एक वैज्ञानिक के रूप में उन्होंने न केवल हमें इस कार्य में भरपूर सहयोग का वचन दिया, अपितु स्वयं अपनी ओर से पत्र लिखकर देश-विदेश के मूर्धन्य वैज्ञानिकों से सहभागिता का आश्वासन भी प्राप्त कराया। वे हमारे अपने हैं, हम सदा उनके प्रति श्रद्धावनत हैं।

प्रस्तुत अंक के सम्मानित सलाहकार एवं सम्पादक मण्डल के अधीत विद्वानों की कृपा के प्रति हम विनयावनत हैं। जिन सुधीजनों ने अपने लेखकीय अवदान से इस अंक को समृद्ध बनाया है, वे साधुवाद के अधिकारी हैं। उनके सहयोग सम्बल के अभाव में यह गुरुतर दायित्व कथमपि पूर्ण नहीं हो पाता। हम उनके कृतज्ञ हैं।

अपने मित्र भौतिकी विभाग के प्रवक्ता डॉ० दीपनारायण त्रिपाठी को किन शब्दों में धन्यवाद दूँ। उन्होंने समय-समय पर अपने स्वाभाविक सहयोग से हमें कृतार्थ किया है। हम इसे अपना प्रेममय अधिकार मानते हैं और आशा करते हैं कि भविष्य में भी उनका सद्भाव बना रहेगा। अपने आत्मीय प्रो० ए० पी० गज्जर, डॉ० रवीन्द्रनाथ मिश्र एवं हीरालाल प्रजापति के हम विशेष आभारी हैं, जिन्होंने अल्प समय में आकर्षक आवरण चित्र बनाकर हमारी कठिन समस्या का समाधान किया। अन्त में हम सीमा प्रेस के व्यवस्थापक की कार्य क्षमता की प्रशंसा करते हैं। हमारी आशा के अनुरूप, समय की न्यूनतम सीमा के भीतर कार्य समाप्ति के लिए प्रेस की जितनी सराहना की जाय थोड़ी है।

एतद् वै तत्

7 नवम्बर 1988
काशी हिन्दू विश्वविद्यालय

विनीत
राम मोहन पाण्डेय

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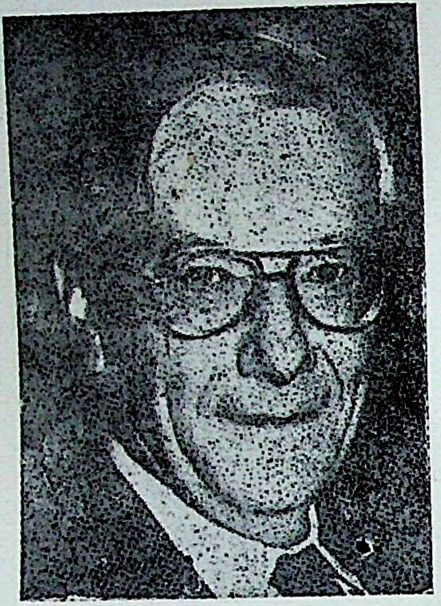


NICOLAAS BLOEMBERGEN

Raman Professor, 1979

Nicolaas Bloembergen was born in Dordrecht, Holland, in 1920 and had his early education in Utrecht. He obtained his Ph. D. for his work on "Nuclear Magnetic Relaxation" at Harvard University under Prof. Purcell.

He made an intensive study of NMR in metals and on ferromagnetic resonance. He was attracted to the maser problem in the midfifties and proposed the three-level and multi-level pumping schemes for steady state pumping of masers.

Bloembergen studied magnetic resonance at high hydrostatic pressures and later extended the technique to EPR studies. He also pioneered the study of the effects of high applied electric fields in NQR and ESR and developed the theory for these effects.

The discovery of the laser brought about a shift in Bloembergen's interest to nonlinear optics in the early sixties. He has made contributions to the field of stimulated Raman Effect, photon magnon interaction and fourwave light mixing spectroscopy. The other branch of his activity concerns the field of infrared laser photochemistry.

In 1981 Bloembergen's brilliant contributions in nonlinear optics and laser spectroscopy were recognised by the award of the Nobel Prize in Physics.

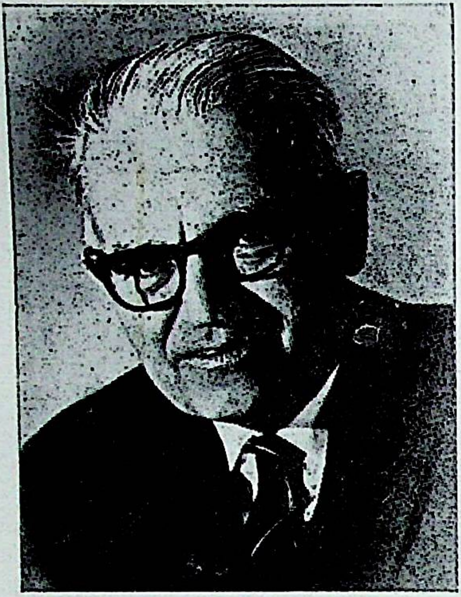
Bloembergen has been on the faculty of Harvard University for the last thirty years. Since 1980 he has held the prestigious Gerhard Gade University Chair. In 1979 he occupied the Raman Chair at the Indian Academy of Sciences, Bangalore, which also elected him as an Honorary Fellow in 1978.

INTRODUCTORY STATEMENT

N. BLOEMBERGEN
Harvard University
Cambridge, MA 02138 USA

The sixtieth anniversary of the discovery of the Raman effect finds this subject in a healthy, active state. The contributions at the ongoing series of International Conferences on Raman Spectroscopy attest to the continuing interest in this field of endeavor. As it is with most other fields related to optics, Raman spectroscopy experienced a 'second youth' with the advent of lasers. The monochromaticity of lasers permitted us to push the resolution in Raman spectra to new limits, and the high intensity of laser beams opened up the field of stimulated Raman scattering. including CARS.

I have recently written a review paper "A quarter century of stimulated Raman scattering", which has been published in the first issue of the International Journal of Modern Physics B1. 1, (1987). I regret that I was not able to contribute something new to this present volume, but I wish all active participants in the field of Raman scattering much success in their future work. stimulated by the contents of this volume.



GERHARD HERZBERG

Professor Gerhard Herzberg-affectionately known as G. H. to a large number of students and students' students -- is one of the seniormost living spectroscopists. Born in 1904 in Germany Herzberg's research carrier has been one long succession of fundamental contributions to the spectroscopy of molecules. His interest in the spectrum of H_2 and its isotopes has been so pervasive that it has formed a constant refrain in his publications. His early work dealt primarily with the spectroscopy of diatomic molecules and resulted in the identification of several new species, in addition to the discovery and elucidation of new aspects of molecular syectra e. g. predissociation and forbidden transitions. His work on forbidden transitions in O_2 (atmospheric bands) and other similar compounds led to an abiding interest in molecules of astrophysical interest.

Herzberg has been an ardent believer in the need for accuracy in any measurment. His work on the Lamb shift of deuterium and helium using optical spectroscopy is a monument to this trait of his work. He recieved the Nobel prize for chemistry in 1971.

Herzberg's set of books on Molecular Structure and Molecular Spectra, Vols I, II, III and IV form a most oomprehensive library on the subject. His little book on Atomic Structure and Atomic Spectra as well his lectures at Cornell University on the Spectra and Structure of Free Radicals provide delightful reading.

REMINISCENCES OF C. V. RAMAN*

G. HERZBERG
National Research Council, Canada

We are celebrating this year the fiftieth anniversary of the Raman effect. To a group of molecular spectroscopists the importance of the Raman effect is so obvious that it needs no further comment other than to say that even today extensions of this important discovery are taking place.

Raman himself would have been ninety years old in November of this year; in other words. he was forty years old when he discovered the effect named after him. This fact may give some comfort to those people who are worried that at age 40 they have passed the best years of their lives.

I met Raman for the first time in 1929 at the General Discussion of the Faraday Society on Molecular Spectra and Molecular Structure, It was a very memorable meeting largely because of the presence of Raman. For me it was the first time that I attended a meeting held in the English language. The first speaker was O. W. Richardson, who unfortunately mumbled and made it quite impossible for me to understand him. The second speaker was Raman. He spoke clearly and lucidly in beautiful English that even I could understand and his enthusiasm was certainly infectious. Just shortly preceding this meeting Heitler and I had discussed the importance of Rasetti's result about the intensity alternation in the Raman spectrum of nitrogen for nuclear theory and Raman showed considerable interest in and understanding of our result.

---

* Remarks made on the occasion of the 50th Anniversary of the Raman Effect at the Molecular Spectroscopy Symposium in Columbus, Ohio. June, 1978

My next encounter with Raman occurred on my first trip to India in January 1957 when I visited Bangalore. During the three days of my stay in Bangalore, Raman made it a habit to come to my hotel in the evening and have a chat. On one of these three evenings he asked me "Have you ever seen the zodiacal light ?." When I answered "No" he said "Come with me", and he took me in his car (chauffeur-driven) out into a dark field, and there was the zodiacal light in all its beauty just as it appears in textbooks. This simple event gave me a strong feeling for Raman's deep interest in physical phenomena and his keenness to share this interest with other people.

My third encounter occurred on my second visit to India in 1963 when Dr. Bhabha had invited the members of the Executive of IUPAP to the Tata Institute. Raman was not present at the meeting but Professor Asundi told me that Raman would be in town to give a popular lecture and asked if I would like to listen to him, and of course I said I would. Raman spoke generally on the colour of natural objects, a delightful lecture. After the lecture he was surrounded by students wanting his autograph. We kept in the background but eventually he discovered us and pushed the students aside to have a chat with us.

Two weeks ago Professor Chandrasekhar, a nephew of Raman, was in Ottawa and put at my disposal a picture of Raman which was painted by Homi Bhabha, the famous Indian theoretical physicist. It was published in "Physics News", the Indian analogue of "Physics Today", in December 1970 following Raman's death. Bhabha, as some of you my know, had a very considerable reputation as a painter apart from his reputation as a top-rate physicist. Chandrasekhar told me that when the painting was completed Bhabha handed it to Raman with the remark "A scientist painted by a scientist" and Raman answered "No, an artist painted by an artist".

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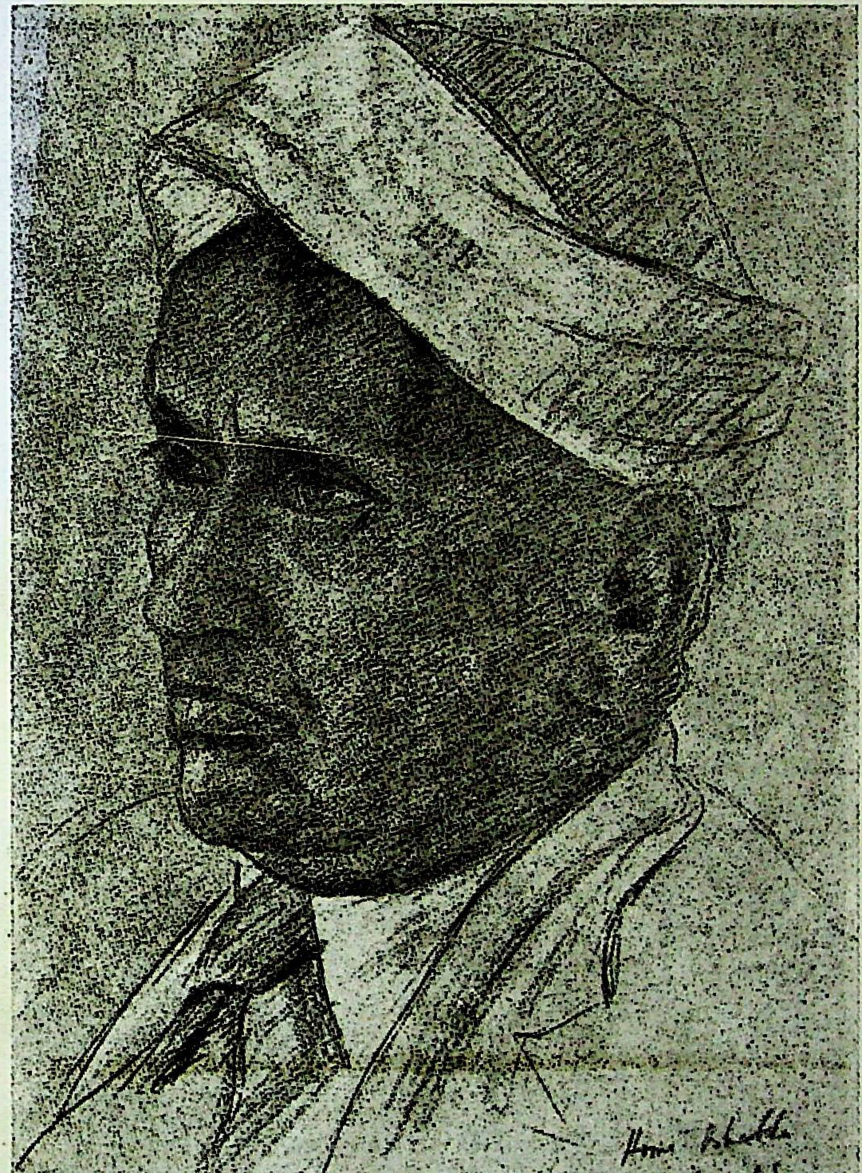
Homi Bhabha
29 June 41

Portrait of Professor C. V. Raman made by Dr. Bhabha

C. V. RAMAN*

S. Ramseshan

I deem it a great honour to have been invited to deliver the first Raman Memorial Lecture. It was suggested that I should talk about Prof. Raman as it would be an appropriate subject this year, the 50th anniversary of the discovery of the Raman effect.

According to the modern view of science, nature can only be described. It cannot be explained. Like many extraordinary natural phenomena, Raman can only be described; he defies explanation.

This talk is not going to be a sociological or psychological study of Raman. I was his student and I knew him well for more than 25 years. For this very reason mine is likely to be a prejudiced view.

Venkata Raman was born on the 7th November 1888 in the small village of Thiruvanaikkaval near Trichinopoly (in Tamil Nadu). His mother was Parvathi Ammal. His father Chandrasekhara Iyer was a teacher in a local school. They had eight children, five sons and three daughters. Apparently Chandrasekhara Iyer did not believe in family planning. Even if he did, and had stuck to the statutory limit, Raman would still have made it as he was the second child, but the present speaker would not have been here to tell this story.

When Raman was three his father accepted the post of lecturer in mathematics and physics in Mrs. A. V. N. College, Vizagapatnam, (in Andhra Pradesh). It is interesting that in spite of a small salary (Rs. 85/–p.m.) and a large family to support, Chandrasekhara Iyer had a good collection of books on physics, mathematics and philosophy written by the masters. He is also said to have played the violin exceedingly well.

Raman matriculated at 11, passed his F. A. (now-a-days called PUC or intermediate) at 13, won a scholarship and joined the Presidency College, Madras. He passed his B. A. at 15 in the first class winning gold medals in English and Physics. He passed the M. A. examination at 18 in January 1907. There is a photograph of him taken when he was in the Presidency College; a thin unimpressive boy with a dhothi draped in the South Indian (cylindrical) style, a cap and no chappals on his feet. There is a story that one of the professors at the college could not believe that this inconspicuous little lad was a student of the Presidency College. He asked Raman whether he had come there by mistake and caused general laughter in class. Very soon his professors found him so remarkably intelligent that they exempted him from attending all the science classes as they felt he had nothing to learn from them. (What understanding professors they were in those days !)

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*This is the text of the First Raman Memorial Lecture, delivered by Professor S. Ramseshan in 1978 at the Indian Institute of Science, Bangalore.

Some of the certificates that his teachers gave Raman are interesting: "The best student I have had in thirty years". "An unusual appreciation of English literature". "A facility in idiomatic expression". "Possessing great alertness of mind and a strong intellectual grasp". "A young man of independence and strength of character", etc.

At the age of 16 while measuring the angle of a prism using a college spectrometer—as thousands of us have done—Raman observed some diffraction bands. He investigated these and they formed the subject of his first publication in The Philosophical Magazine (London) in 1906. This was followed by a note in the same journal on a new experimental method of measuring surface tension.

These papers were communicated by the author himself and contain no acknowledgement of help received from any one. It is also important to note that the Presidency College was at that time a teaching institution with no tradition whatsoever of research.

When he passed his B.A. Examination his teachers suggested that he should go to England for further studies. But the Civil Surgeon of Madras ruled it out by disqualifying him medically saying that the rigours of the English climate would kill him. Raman is known to have said later "I shall ever be grateful to this man". In 1906 after his M. A. his teachers advised him to appear for the competitive examination which chose civil servants for the Finance Department. He passed the examination topping the list again.

Against all conventions of the time he arranged his own marriage with Lokasundari, who was then 13 years old. The story has it that on the first occasion he saw her, she was playing on the veena the Thyagaraja Keertana "Rama in samanam evaro". We shall never know whether it was by intent or by accident. Anyway, she insists that she still does not know if Raman married her for the extra allowance of Rs. 150/- which the Finance Department gave to its married officers !

In 1907 the young couple went to Calcutta. He joined the Finance Department as Assistant Accountant General. He wes then 18½ years old.

They rented a house in Scots Lane, off Bowbazaar Street. Within 6 or 7 days of his reaching Calcutta, while on his way to work by tram, he saw a sign which read The Indian Association for the Cultivation of Science. The address was 210, Bowbazaar Street. On his way back he knocked on the door, it was opened, we are told, by one Ashutosh Dey who was to be Raman's assistant for 25 years, the faithful Ashu Babu. Raman saw a dusty lecture hall and a large laboratory with a lot of even dustier equipment, mostly of the demonstration type.

Ashu Babu took Raman to Amrita Lal Sircar, the Secretary of the Association, who promptly handed over the keys of the Association to Raman when he heard of his plans to use it for research.

The Association had been established in 1876 by Amrita Lal's father Mahendra Lal Sircar, a man of vision, who wanted to have an institution which was a combination of the Royal Institution of London and the British Association. It started off well. At every annual meeting Mahendra Lal advocated the importance of the cultivation of science by original research. There were many popular and scientific lectures in the early days but no research of any type. Subsequently the institution had decayed, and in 1902 a despondent Mahendra Lal had declared, "I do not know how to account for the apathy of our people towards the cultivation of science" A few weeks before his death he stated "Younger men must come and step into my place and make this into a great institution".

At this time Raman had just passed his B. A. Examination. In three years he was to discover the Association and turn 210, Bowbazaar Street into one of the important centres of original research in the world.

Young Lokasundari tells us of the routine–5.30 a.m. Raman goes to the Association. Returns at 9.45 a.m. bathes, gulps his food in haste, leaves for his office, invariably by taxi so that he may not be late. At 5 p.m. Raman goes directly to the Association on his way back from work. Home at 9.30 or 10 p.m. Sundays, whole day at the Association. Truly not an exciting life for a young bride.

She tells delightful stories of those days. There was one, of her going to the beautiful church at the end of Scots Lane when exploring the neighbourhood—but the brahmin cook (they had one, remember the Rs. 150/-married allowance) left because he did not want to have any truck with people who go to church !

There is an interruption to Raman's work at the Association but not to his scientific activity. He is transferred to Rangoon (1909) and Nagpur (1910). At both places he converts his home into a laboratory and continues his work. He is back in Calcutta in 1911.

He and Ashu Babu are the only workers at the Association. Even so publications pour out. He starts the Bulletin of the Indian Association wherein he publishes massive monographs. In 1917 the Bulletin becomes the Proceedings and much later the Indian Journal of Physics.

What are the problems he tackles ? It is remarkable that every one of them is connected with his direct experience thus arousing his curiosity. He has heard his father play the violin. He worked with the sonometer and done Melde's experiment in college. So follow his papers on the bowed string, the struck string, the maintenance of vibrations, resonance, aerial waves generated by impact, the sounds of splashes, the singing flames, music from heated metals and many others.

Ashu Babu is his only collaborator and his name appears as a joint author in many papers. Raman is proud that there is a paper in which A. Dey is the sole author: published in the Proceedings of the Royal Society by his Ashu Babu who has never entered the portals of a university !

He investigates whether his feeling that the veena produces the most exquisite musical sound is due to sentiment or has a sound physical basis. The bridge of the veena is so cunningly constructed that the Helmholtz law, that the position at which the string is plucked cannot be a node, is violated. Thus this instrument produces innumerable harmonics making its sound closest in harmonic content to the human voice.

He knows that the normal stretched circular membrane as found in the western drum is "unmusical and just a noise producer". His sharp ear detects musical overtones in the sound of the mridangam and the tabla. He discovers that the heterogeneous loading of their membranes can produce harmonics—so that in the hands of the masters, the Indian drum is similar to a stringed instrument.

He publishes a beautiful paper on acoustical knowledge of the ancient Hindus, for the Ashutosh Mukherjee commemoration volume. He has become a world authority on sound and musical instruments.

A little earlier Sir Ashutosh Mukherjee, the Vice-Chancellor of the Calcutta University, offers him the Palit Chair of Physics. Raman decides to accept the offer for a salary less than what he is getting.

It is of some interest to know whether at this time he was succesful as a Finance Officer. Apparently he was, for he has been congratulated many times by his "superiors" for his outstanding work. They are reluctant to let him go.The Member (Finance) in the Viceroy's Council writes: "We find Venkataraman is most useful in the Finance Department being, in fact, one of our best men".

Raman' s decision produces consternation in the establishment. There may soon be Indianisation, they tell him. As one of the best officers, he may even end up as Member (Finance) in the Viceroy's Council - who knows ? But Raman's mind is made up:

There is problem, however, because one of the requirements for appointment to the Palit Chair is to have been trained abroad. Raman refuses to go to England to be "trained". The impasse is broken by Sir Ashutosh changing the provisions of the endowment. What an administrator !

In 1919Amrita Lal Sircar died and Raman became the Honorary Secretary of the Association having thus two laboratories to work in. He takes research students for the first time.

Under pressure from Sir Ashutosh he goes to Europe in 1921, as a delegate to the Universities Congress held that year in Oxford. During this brief visit he meets the most famous scientists of England, J.J. Thomson, Rutherford, Bragg senior and others

Raman tells a story later how moved he was when Rutherford recognised him sitting in a bench at a lecture and asked him to come and sit next to him.

Like any good tourist he takes in the sights of London and visits St. Paul's Cathedral. He marvels at its whispering gallery, does a few experiments, and publishes two papers - one in Nature and the other in the Proceedings of the Royal Society.

It was on this voyage that Raman came face to face with the grandeur of the Mediterranean sea, its beauty, its moods and in particular its blueness. The more he saw of it, the more did his wonder grow.

Lord Rayleigh, who had explained the blue of the sky as due to scattering by the atmosphere, dismissed the blue of the sea with the statement "The much admired dark blue of the deep sea....is simply, the blue of the sky seen by reflection". Raman demolished this idea by an extremely simple experiment during the return voyage. He quenched the reflection of the sky in the sea by observing it at the Brewsterian angle through a polarising nicol prism. Even with the sky reflection so extinguished,he saw the surface of the sea glowing with a vivid blue which appeared to emerge from inside the water indicating that the blueness of the sea was due to scattering by water.

What a sight he must have been on the ship—this turbanned brown Indian, with his nicol prisms and cardboard tubes, running from side to side of the ship, collecting sea water in bottles from the depths of the oceans. All this while others were busy playing shuttlecock and battledores -the real mad scientist of fiction.

Even on board ship he felt that the Einstein-Smoluchowski concept of thermodynamic fluctuation-which was developed to explain special optical phenomena near the critical point could be extended to explain molecular diffraction in liquids. On his return to India he started three most fruitful lines of investigation:

1. The scattering of light by liquids.
2. The scattering of x-rays by liquids.
3. The viscosity of liquids.

Many here may not know that the earliest work on the scattering of x-rays by liquids was done in India. Raman and his group developed an effective theory and confirmed the shapes of many molecules and deduced the nature of their aggregation in the liquid state. Raman once said wistfully "We were so preoccupied with light scattering that we did not apply the idea of Fourier transforms to x -ray scattering in liquids although we were so close to it". This was done later by Zernicke and Prins in 1927- The famous Raman-Ramanathan paper was in 1923.

In 1923 he advanced a theory of viscosity which was quite a success. It was used by Staudinger the famous polymer chemist to explain the viscosity of polymers.

Within a few weeks of his return from England he (and Seshagiri Rao) had measured the intensity of the molecular scattering of light from water. They established that the Einstein-Smoluchowski concept of thermodynamic fluctuations could be extended to explain molecular scattering almost quantitatively. As a result many of his students were put to studying molecular scattering in liquids and vapours.

It was in 1922 that he wrote and published his monograph "The Molecular Diffraction of Light". In it he raised such questions as to what would happen in a black body enclosure if the exchange of energy took place by molecular scattering. He considered in detail how energy could be transferred between the quantum of light and the molecule. He seems to have been convinced that the quantum nature of light should reveal itself in molecular scattering. We note all this was a year before the discovery of the Compton effect.

In April 1923 K. R. Ramanathan, the oldest and among the most distinguished of Raman's students, at Raman's suggestion, made a serious study of the scattering of light in water. Sunlight was focussed on the liquid and the scattered light was seen as a track in the transverse direction. A system of complementary filters was devised, each filter completely cutting off the light transmitted by the other. When the incident light was passed through one, and the scattered light viewed through the other, no track should have been visible, if there had been no change of colour in the process. But the track could be observed. This was attributed to a "weak fluorescence" due to impurities which were believed to be present. This "weak fluorescence" was not completely depolarised (as true fluorescence should have been) and that the amount of depolarisation changed with wavelength.

Ramanathan wrote much later : "Raman was not satisfied with the explanation that it was due to fluorescence. He felt that it was characteristic of the substance and wondered whether it might not be akin to the Compton effect in x–ray scattering" (where a change in wavelength of x–rays scattered by atoms had just been discovered that year.) Even after repeated slow distillation of the liquids in vacuum the "weak fluorescence" persisted undiminished. The same effect was also observed later in many organic liquids, by K. S. Krishnan another of Raman's distinguished students who had just joined him.

In winter of 1927 Raman went on a vacation (or perhaps a lecture tour) to Waltair. The Compton effect was on his mind. He had calculated that the true Compton scattering could not be observed at optical wavelengths. He considered the interaction of x–rays with the electrons of the atom—and using the concept of fluctuations, which was so successful in explaining the molecular scattering, he derived the relationship now famous as the Compton–Raman formula. The derivation was completely classical wherein Raman showed that the coherent scattering (corresponding to Thomson scattering in x-rays and to Rayleigh scattering in light) is proportional to the square of the number of electrons in the atom whereas the incoherent scattering (Compton scattering) is proportional to the number of electrons.

In January 1928 Venkateswaran who was on the task of purifying many liquids made the remarkable observation that in pure glycerine the scattered light was greenish in colour instead of the usual blue, and the radiation was strongly polarised.

In the last week of January Raman apparently decided to settle the issue. He asked K. S. Krishnan who has been doing excellent theoretical work on mechanical, electric and magnetic birefringence to take up experimental work again and to follow up Venkateswaran's observations. Raman persuaded Krishnan that it was not healthy for a scientific man to get out of touch with actual experimentation for any length of time (Krishnan's last experimental work was done 18 to 20 months before).

Krishnan set up the experiment for the study of the scattering of light in organic liquids and vapours—but this time he used larger lenses (7 inches diameter) so the intensity of the track was very much greater. On the 7th February he noticed that all his liquids exhibited the famous "weak fluorescence'' observed by Ramanathan and further the polarisation of the "fluorescent" light was greater the smaller the anisotropy of the molecule.

Professor Raman (according to Krishnan) personally verified that all the liquids exhibited this phenomenon. He records that Raman rushed to his house quite excited to tell him that he was certain that their observations in the morning were related to the Kramers-Heisenberg process they were looking for all these years. On the 16th February they sent a note to Nature repeating the arguments used in Raman's classical derivation of the Compton effect and suggesting that "the modified radiation could arise from the fluctuations of the molecules from the normal state".

While the analogy with the x–ray case had been made much closer, it was apparent that the phenomenon was not fully understood and the observations continued, Raman making most of them himself.

On the evening of the 27th Raman decided to view the "fluorescent track" through a direct vision spectroscope but by the time Ashu Babu set it up the sun had set. Next morning the first observation was made of what is now known as the Raman effect. The spectroscope showed that the track contained not only the incident colour but at least another separated by a dark space.

Ashu Babu was immediately asked to set up a mercury arc, a light source known for its sharp monochromatic lines. Using a filter in the incident light which cuts off all the visible light longer than the indigo 4358 A. U. line the direct vision spectroscope showed not one but two sharp lines in the blue-green region.

The announcement of the discovery was made to the Associated Press the following day, the 29th of February 1928.

When a photograph was taken of the spectrum using a Hilger Baby quartz spectrograph, the shift in frequency of the new line from the incident one was identified with the change in the energy of the vibrational state of the molecule. Further, modified lines were observed having frequencies both lower and higher than that of the incident light indicating that the incident photon could gain or lose energy when scattered by the molecules.

Story goes that the note to Nature sent by Raman announcing the discovery on March 8th was rejected by a referee but published anyway by the editor.

The following is an extract of the cable to Nature from Prof. R. W. Wood, the distinguished optical physicist of Johns Hopkins University, U. S. A:

"Prof. Raman's brilliant and surprising discovery; I have verified his discovery in every particular. Raman's discovery thus makes it possible to investigate remote infrared regions hitherto little explored, It appears to me that this very beautiful discovery which resulted from Raman's long and patient study of the phenomenon of light scattering is one of the most convincing proofs of the quantum theory of light".

Before long many laboratories around the world took up the study of the Raman effect in simple molecules. But in Raman's laboratory the accent was on the study of more fundamental problems connected with the physics of the liquid and solid state using the Raman effect as a tool.

Raman was awarded the Noble Prize for his work "on the diffusion of light and for the discovery of the effect named after him". His Nobel lecture is a masterpiece of composition relating the exciting story of the persistent efforts from 1921–1930 giving a detailed account of the contribution made by each of his collaborators

There are two stories that are indicative of the character of this incredible man and his supreme selfconfidence. Raman was elected a Fellow of the Royal Society in 1924. At the meeting to felicitate him, he is known to have said—while he appreciated the honour done to him he did not consider it the ultimate and that he would get the Nobel Prize for India within 5 years !

Nobel Prizes are announced in the second or third week of November. The meetings of the Nobel Committee are held in the highest secrecy and the awards are announced in November about a month before the prize giving ceremony in mid-December. It would have been surprising enough that Raman could leave by steam ship after receiving the news by telegram to reach Stockholm in time for the ceremony. It is now a historical fact however that Raman had booked two tickets for himself and his wife in July that year to enable them to reach Stockholm in early December !

In 1933 Raman was offered the Directorship of this Institute, which as you all know was started by that visionary J. N. Tata whose memory is also being honoured today. Raman was at first in two minds about taking it up, but later decided to accept the offer. Before leaving Calcutta he made sure that his brilliant pupil K. S. Krishnan was appointed the Mahendra Lal Sircar Professor at the Indian Association. Regarding Raman's move to Bangalore, Fermor (the Director–General of the Geological Survey) and the President of the Science Congress that year said "At present Calcutta may be regarded as the centre of scientific research in India. But with the transference to Bangalore of one of the leading investigators. Calcutta will have to guard her laurels".

This was the year many famous scientists were fleeing Germany to escape from the tyranny of Hitler. No sooner had he come to Bangalore then Raman made attempts to get some of them to India. He succeeded in appointing Max Born to an extraordinary chair of physics which he created at the Institute. There is a letter from Schroedinger, the originator of wave mechanics, saying that Raman's offer had arrived a bit too late as he had just accepted an offer from Dublin–regretting that he could not settle in the land of the Upanishads ! Ewald, Peierls, Kuhn and many others were also in Raman's list. Years later I once asked him about his attempts to bring these scientists to India. He replied that he had always been against young Indians going abroad to be initiated in scientific research because it would have been done in a an evironment so completely different from what exists in India. This type of training could have made them useless in our country. If great minds like Born and Schroedinger who were seeking a country to adopt had been provided with a home here, a real scientific movement could perhaps have been started in the country. Unfortunately Raman was prevented in succeeding in this attempt.

In inviting these scientists, he had, characteristically not taken permission of the management of the Institute. For this and other such reasons he was forced to resign from the Directorship of the Institute but he managed to retain his Professorship. I am not familiar with the complete story of this "demotion" but I certainly plan to look into the history of this incident. The formal charges were, in any case, definitely flimsy. While Raman could admittedly be difficult, one wonders whether it was not just due to the "scientific politics" of that time.

"What is highest is Envy's mark" said Ovid.

In 1934 Raman started the Indian Academy of Sciences and the best young scientists from all over India were elected as Fellows. They began publishing in its journals. It is remarkable that for twenty years right upto 1954 the Proceedings of the Indian Academy was considered among the top journals of the world in physics and chemistry. The annual meetings of the Academy, which Raman used to call his travelling circus, were held in university towns. The most distinguished scientists of the country were always there discoursing and lecturing. But Raman was always the star performer.

I particularly remember the meeting of 1941 in Nagpur where I was a student of the B.Sc. (Hons.) class. K. R. Ramanathan was there, and so was Bhabha. I even remember young Vikram Sarabhai, and there were a host of others. It was a coterie of scientists talking only science. It was so exciting for me and all the young people from the university. Raman, as always, gave the presidential address, and ended the three-day session with a popular lecture. He always drew very large audiences, and this time there were more than 5000 to listen to him. Every man and woman, every boy and girl went back dazed, feeling they had discovered the beauty and the simplicity of science.

During my career I have heard many, many scientists talk and lecture. But Raman in his hey--day was perhaps best. This opinion, I know, is shared by many of my generation. What was it that made his lectures so gripping ? It was not just his mannerisms or his humour--he made his audiences roar with laughter. To him, giving a lecture was clearing up things in his own mind. He talked of only those things about which he felt intensely, of those things which he understood or wanted to understand. He saw things in their simplest and most basic elements. He made the audience feel that they could have seen it all by themselves (which of course they had not).

He was perhaps the greatest salesman science has ever had in this country. How many gifted young men of the last generation took to science because of having listened to him once ?

A word about him and his students. He usually selected very talented young men (and on a few occasions women) to work with him.

So powerful was his influence that his students rose to heights which they themselves could not have imagined possible. He was like a conductor who extracted the best music from his orchestra. It was not uncommon that some students who had done extremely well when they were with him, once deprived of his influence were never heard of again !

He used his personal prestige and that of the Indian Academy to encourage scientific talent, wherever it was found and in whatever field it showed itself. From 1924 till about 1954 (when "big science" was established in India) he was one of the main sources of encouragement for scientific talent in the country. In this respect his service to the nation was unique.

As with the Indian Association he made the Physics Department of this Institute a centre of world renown. He worked on such delectable things as the plumage of birds, the colours of shells, the hues of old iridescent glass, and of soap bubbles. Along with Nagendra Nath, he propounded the now famous Raman–Nath theory of the diffraction of light by ultrasonic waves based on a concept so simple and so elegant. A plane wave of light when it passes through an ultrasonic wave field is speeded up in regions of rarefaction and slowed down in the regions of compression to emerge as a corrugated wave front. This idea cleared the air of many of the theories that were extant and was hailed all over the world. The year after the Raman–Nath papers appeared in the Proceedings, the circulation shot up noticeably.

His school again had a renewed look at the scattering of light by liquids. According to Brillouin, thermodynamic fluctuations in the liquid can be broken up into waves (the Fourier components) which would scatter light with an associated Doppler shift from which the velocity of these waves could be measured. Such measurements were made by Raman's group. But what was more exciting was the discovery that viscous liquids almost behaved like solids at these high frequencies sustaining not only longitudinal but also shear waves. They were able to get the rigidity modulus for these liquids at these high frequencies !

Raman's interest in diamonds is well known. As a direct result of this, his school carried out pioneering studies of the thermo–optic behaviour of solids, their photo–elastic, magneto–optic properties, fluorescence, and second order Raman effect, infrared spectroscopy, etc. It is perhaps not well known that x–ray topography was discovered in this laboratory while studying the imperfection in diamond.

In 1948 he retired from the Indian Institute of Science and was made a National Professor. He had hoped to start a small institute for himself with his life's savings, where he could retire and enjoy science. But it so happened that he lost most of his savings in a "south sea bubble" investment. He was sixty then and to anyone else it would have been an impossible situation. But Raman was undeterred. He went round the country and collected money.

"Our greatest men were beggars" he said, "The Buddha, Shankara even Gandhi". He succeeded in collecting enough to start the Institute but not to sustain it.

He then launched courageously on a new project. Advised and aided by an old student, he used what remained of his savings to start a couple of chemical factories, the dividends from which were sufficient to support his Institute and to keep it independent of government grants. Raman was never a member of too many committee, but on his retirement he resigned from every one of them. There is a story concerning his reactions when a feeler was sent out to see whether he would like the Vice-Presidentship of India. He is reported to have had a hearty laugh and asked "What shall I do with it".

For some years there was no equipment or even electrical power in his Institute. He arranged his famous mineral and crystal collection and commenced his researches on the colour and iridescence of minerals and gems. It is remarkable how much information he could extract by just sending a beam of light into a gem and observing the scattering. This led him on to his classical papers on the optics of heterogeneous media.

He took students but this time with greater discrimination, and once more he made his laboratory into a great centre of research. There were many outstanding research publications from the Institute on the generalised theory of interference, the theory of optical activity in crystals and a variety of other subjects.

It was during this period that he launched upon his researches on the physiology of vision and on floral colours. He was happy surrounded by his exquisite roses, the jacarandas and the bougainvilleas, the hibiscus and the morning glories and enjoyed studying them.

Perhaps the least understood and the most criticised phase of Raman's life was when he suddenly chose to make himself a recluse. He refused to accept even the marginal support he was getting from the Governmet. Two ministers who visited him once to offer support were told "Why do you want to despoil the only oasis of freedom in the country". He built high walls around the Institute and put up a prominent sign stating that visitors were not welcome. His attitude particularly towards the Government, became one of utmost cynicism.

To those who knew him, he was a soul in agony. He was veritably like Timon of Athens—bitter and cynical.

To Raman, scientific activity was the fulfilment of an inner need. His approach to science was one of passion, curiosity and simplicity. It was an attempt to understand. To him science was based on independent thought, combined with hard work. Science was a personal endeavour, an aesthetic pursuit and above all a joyous experience.

The Indian scientific scene of that time presented to him a very strange picture. The establishment seemed to believe that scientists cannot be grown in the country as they sent all their bright young students abroad for 'training'. He saw the expenditure of large sums of money—in the belief that science, and therefore technology, will automatically be created. He saw the replacement of quality by quantity. He saw the choice of research topics—dictated mostly by foreign fashions and this hurt him most.

I shall make no value judgement here, but we can imagine what he would have felt. A total negation, in the name of science, of all the values he had lived by. He must have felt that his example had been totally in vain and he blamed the establishment for it.

"My life" he once cried, "has been an utter failure". "I thought I would try to build true science in this country. But all we have is a legion of camp followers of the West"

To my mind the agony of Raman can only be compared to that of Gandhi in Noakhali when he too found that all his life's work was as nought, the apostle of non-violence witnessing his countrymen beating each other to death.

It was in this phase that Raman resigned from the Royal Society of London.

Raman did come out of the slough of despond finally. Almost every day he was seen taking school children and college students round his Institute regaling them with stories and showing them experiments. He began accepting lecture engagements. His charisma was still Potent with the younger generation. He attracted enormous audiences, and university halls began overflowing again. He made fervent pleas to the Government to improve school and university education and university research.

He said "when we want to achieve—whether it be in science or in anything else we must first learn to use the resources we have in plenty. As a nation what are the resources we have in plenty—human beings of whom at least a third are young. This is our real strength. If they are enthused and if they are instilled with a spirit of adventure, the sleeping giant will wake up and we can conquer the world"

Raman was, of course, the supreme egotist. But in private conversation he often showed such an unbelievable scientific humility as to make one wonder which was his true self. He always told people what he felt and in this process hurt many. He was a man of emotion and he could get violently angry. Some of us still remember, how he wept like a child during one of the Academy lectures when pictures were shown of children of our land suffering from nutritional ailments. He had an incredible sense of humour and he could keep us roaring with laughter just describing what could have been commonplace incident.

He was a very simple man, quite childlike—sometimes even childish.

The science administrators of today would even think him naive. For example he believed that the only method of promoting science was by doing it, and to him the professional organisers of science were an abomination. "For such people" he said "the so-called organisation of science becomes more important than science itself or its values".

To him the simplest observations that he could make by just looking around him were worthy of the deepest scientific investigation. He demonstrated over and over again that a deeper understanding of these every day phenomena paved the way for the discovery of fundamental laws. He relied greatly on intuition—in fact Max Born once said "Raman's quick mind leaps over mathematics"

Anyone who met him could not but be struck by his zest for life. Born refers to this in his letter to Lord Rutherford written in the later half of the thirties. Born says "there is no Indian physicist of the rank of Raman. No man can compare with him in regard to vigour or intensity. This European intensity which Raman exhibits to a marked degree would make any average Indian scientist suspicious of him".

His exhuberance was infectious. Chatting with him for some time was like taking a tonic.

To those of us, who knew him well, what struck us most was his intense love of and preoccupation with nature—the colours of birds, the sheen of the beetles, the blue of the sky, the spectacular hues of the coronas and the glories that surround the Sun and the Moon, the extraordinary beauty of minerals, crystals and gems–not only thrilled him but formed the subject matter of his scientific studies.

A few months before he died, I remember, while walking with him one evening amongst the eucalyptus groves that he loved, he stopped me in his characteristic manner and pointing towards the sky said: "Have you seen anything so beautiful ?"

Above, one saw little wisps of multi-coloured clouds passing close to the Moon, which gleamed over the shimmering leaves of the trees—trees which appeared like nature's own cathedral.

"This is happiness" he said. "That we should be alive, and that we should be endowed by nature the faculty to perceive this fleeting vision of beauty—this is happiness indeed?'.

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RAMAN EFFECT & SCATTERING OF LIGHT : EVOLUTION OF RAMAN'S THOUGHT

D.K. RAI

The discovery of the 'Raman Effect' by C. V. Raman in the laboratories of the Indian Association for the Cultivation of Sciences at Calcutta in Feb. 1928 is now universally regarded as one of the basic discoveries of this century. During the early days of this discovery, however, there were attempts both wittingly and unwittingly to either lessen the contribution of Raman by regarding it as a fluke or by interpreting it as just a verification of some already known theoretical results. The usage of the term Smekal–Raman Effect for this observation by the German speaking science media for several years is an example that obviously comes to mind. An article by Darwin[1] was obviously an attempt of the first kind which so irked Raman as to prompt him to publish a comment on this paper[2] in order to put the record straight. Furthermore, Max Jammer in his delightful and erudite book[3] "The Conceptual Development of the Quantum Theory" quotes an incident in a meeting where Compton presented his recent discovery of the effect known by his name. His own interpretation of this result which is now acknowledged as the correct one was severely criticised by Duane and a lively discussion about the two alternative interpretations–one quantal following Einstein and the other classical wave theoretical–took place. According to Jammer, Raman commented "Compton you are a good debater but the truth is not in you". As we will see below this is a strange comment coming as it does from a person who several years ago in a hastily written monograph[4] has clearly indicated that there might be experimental observations in light scattering which require the use of Einstein's photon concept in place of the classical wave theory. It seemed therefore, worthwhile, specially in this centenary year of the birth of Raman and the 60th anniversary of the discovery of the effect, to retrace the evolution of Raman's idea on scattering of light by molecules and about light in general as exemplified by his publications in this field. The discussion is based almost entirely on the collection of Professor Raman's papers in "Scattering of Light"[5] published by the Indian Academy of Sciences in 1978. My deepest thanks are due to Professor Ramaseshan for bringing this collection to my notice and to Professor D. D. Pant another of Professor Raman's old students for encouraging me to undertake such a study.

As will be apparent at some places the continuous evolution of Raman's thoughts can not be traced through the published papers (of which he is either an author or co-author) alone and a more critical analysis can be performed only if more material e. g. diaries, note-books, scientific correspondence etc. becomes available. The discussions given in this paper are therefore by necessity not complete. I hope to be excused for this deficiency.

Initial Work On Light Scattering at Calcutta :

The origin of Raman's interest in light scattering by gases and vapours, liquids, amorphous and crystalline solids is not apparent from the published papers. In his Nobel Prize lecture[6] Raman himself has emphasized the impact of the colour of the Mediterranean sea during a voyage to Europe in the summer of 1921. This journey, which was undertaken at the behest of Sir Asutosh Mukherjee, the enlightened and far seeing Vice-Chancellor of the Calcutta University who had recently appointed Raman to the newly and richly endowed Palit Professorship in Physics, in order to circumvent the requirement of the incumbent of this chair having been trained in one of the European centres of learning, certainly is of great significance for the subsequent work by Raman and his group. However, two facts militate against taking this point of time as the origin of Raman's interest in scattering of light. Firstly as pointed out by Ramseshan in his introduction to the collection of Raman's papers on Scattering of Light,[5] Raman had prepared himself in advance for the observations that he subsequently carried out during the voyage. Secondly, there is a paper[7] dealing with the importance of Doppler effect in light scattering which was published in 1919 almost two years before the journey was undertaken. We are inclined to agree with Ramaseshan that Raman must have been attracted by the colours of the sky and the sea from his early schooldays in Madras. We must remember that the unpolluted Bay of Bengal in those days must have been as blue as any other sea. I hope some one with access to the personal papers of Professor Raman will endeavour to shed some light on this important question.

One point, however, seems very clear. Whatever may have been the cause of Raman's interest in the light scattering phenomena the association of the two Lord Rayleigh's–specially the elder one, with this study had a tremendous impact on his mind. Biographers of Raman have mentioned the profound sense of respect Raman felt for Rayleigh, Helmholtz, Newton and the like, whom he regarded as something more than mere scientists. Any work which dealt with some aspects of Rayleigh's own work on light scattering merited examination.

Raman must have been thinking about Rayleigh's theoretical derivation of his (Rayleigh's) scattering formula from much earlier, since he recognised that a crucial requirement for the validity of this theory was the additivity of the light energy scattered by the different molecules of a gas. Rayleigh in his treatment had simply stated that since the molecules in a gas are distributed in a chaotic fashion the secondary waves emitted from them, on being irradiated with an incident pulse of light, have no definite phase relationships with one another and therefore it is the intensity of these secondary emissions which ought to be added rather than their amplitudes. The vagueness in this statement troubled Raman seriously because experimental observations were in agreement with Rayleigh formula. These obviously troubled Larmor and he argued in a note[8] published in Jan. 1919, that the random nature of the phases is a consequence of the chaotic thermal motion of the molecules, since a moving molecule will experience a slightly different frequency of the incident radiation as compared to a stationary one. Raman[7] points out two difficulties with this argument—firstly for collinear scattering the Doppler effect will not contribute to any change of frequency as for as laboratory observations are concerned and the dependence on the angle between the direction of incidence and direction of scattering will have to be considered. Secondly and more importantly, as pointed out more explicitly by Raman in his monograph[4], this would mean that at small distances from the scattering system, the secondary emission from different molecules are in phase and only after travelling some distance (estimated in a typical case as few tens of cms) they get out of phase. This if true, would give the peculiar result that the intensity of scattering is very small at small distances from the scattering centre and becomes large after some distance. He gave detailed arguments based on the fact that there is no effect of the motion of the source on the speed of light-to show the utter ineffectiveness of Doppler effect in yielding random phases.

The matter is serious euongh to merit a good justification and Raman provides it in his characteristic style. He asserts[4] "In order that the phases of the scattered wave coming from different individual molecules should be completely fortuitous, it is clearly necessary and sufficient that the distribution of molecules in the space enclosed .... should be itself entirely fortuitous". In other words "If the probability that a given molecule is found within a small specified volume is independent of the presence of any other molecules". He concludes that Rayleigh's formula is valid in cases where Boyle's law is valid.

One more minor modification of Rayleigh's law is suggested by Raman and that is the replacement of $(\mu - 1)$ being regarded as proportional to the density by the Lorentz-Mosotti law $\frac{\mu^2 - 1}{\mu^2 + 2} \propto \varrho$.

Raman's early training in the Presidency College, Madras, would have certainly given him and his companions ample opportunity to lookout to the sea, marvel at its deep blue colour, as well as the riot of colours in the sky and their reflections in the limpid waters. The difficulty in seeing objects at a distance must have been treated in his brain as one more deficiency or fraility to be overcome. It is remarkable, that he noticed the improvement in the visibility of distant objects when one uses a nicol, properly oriented, before one's eyes.[10] The nicol prism helped in cutting out the light reflected from the surface of the sea and made it possible for Raman to see the molecular scattering of light in water.

The paper to Nature[11] that he submitted from Bombay Harbour aboard S.S. Narkunda on Sept. 26,1921 is an important step in our journey. It reports the main results of the observations that Raman had carried out on his return journey to India and reports three major findings all of which were followed up in later work by his group. First and foremost he concerns himself with the remark of Lord Rayleigh "that the much admired blue colour of the deep sea is but a reflection of the colour of the sky and has nothing to do with the colour of water". Raman notes that the surface reflection can be easily suppressed by using a suitably oriented nicol prism in front of the observer's eye and when the sea is looked at in this way the "blue colour of the sea is of such fullness and saturation that the bluest sky in comparison with it seems a dullgrey". In fact there is a greater strengthening of the shorter wavelengths in light scattered from water as compared to air. Raman also determined the variation of the colour when the azimuth of observation is changed and at a certain angle of observation sun's rays were seen as going deep (several hundred feet) into the sea. This last observation removed all doubt as to the molecular nature of the scattering.

In a following paper[12] submitted to Nature within a month of his arrival in India, Raman reports his success in deriving a theoretical explanation of the observed light scattering from liquids in terms of a theory of 'fluctuations' used earlier by Einstein and Smoluchowski to explain the opalescence observed near critical points.

We then come to a detailed paper[13] in the Proceedings of the Royal Society of London published in 1922 but submitted on Nov. 23, 1921 less than 2 months after the arrival of Raman in india from his European tour. The objective of the paper is "to point out the part played by molecular diffraction in another of the great natural optical phenomena, that is, the colour exhibited by large masses of clear water, when illuminated by sunlight and viewed from above, the depth being so great as to provide a perfectly black background for observation".

This quotation from the introduction of this paper sets forth three features of Raman's scientific work. He is interested in a "great natural optical phenomenon" which is commonly seen, to provide a satisfactory explanation of the same. His source of incident radiation is the sun-the most luminous source. The importance of a "perfectly black background for observation," is emphasized by implication. Those who are familiar with "The physiology of vision"[14] which embodies the description of a much later series of experiments conducted by Raman would see a continuation of the three themes again and again. His confidence in visual affirmation of measurements performed in other ways was phenomenal.

After stating his object Raman summarizes the status of this problem in the available literature. In his inimitable style he characterizes this status as "peculiar" in that even the reality of the phenomenon is doubted. He quotes Rayleigh—'an eminent authority' on one hand and on the other those who have had wide opportunities to view the sea. It is characteristic of Raman not to be awed by the authority on one hand nor to dismiss the views of a non-authority on the other. In his summary of the prevailing opinion he is candid and factual eventhough his own observations are at variance and he proves the total incorrectness of this view in the course of this paper.

Raman at first summarized the Rayleigh theory for molecular diffraction of light in gases. In his view the essential aspect is the assumption that the effects of individual molecules are statistically independent and hence additive except in the direction of the incident light beam. The justification for this assumption is provided by the existence of large thermal motions in various directions as emphasized by Larmor and by Raman himself. He also notes that the Rayleigh law is valid also for very dense or highly compressed gases. However, the theory is not expected to be valid for liquids because in the latter the molecules are more closely spaced and have a much smaller freedom of movement.

Smoluchowski had used the "theory of fluctuations" to explain the optical phenomena seen near the critical points. The theory regards the medium as undergoing small local variations of density due to irregular movement of the molecules and this density fluctuation results in a certain proportion of the incident light being scattered, It is found that the fraction of the light diffused by one cubic cm of the fluid in a direction at right angles to the incident direction of the light beam is given by

$$\frac{\pi^3}{18} \quad \frac{\beta}{\lambda 4} \quad \frac{RT}{N} \quad (\mu^2 - 1)^2 \, (\mu^2 + 2)$$

For liquids β is the compressibility, μ the refractive index, λ the wavelength of incident light and R, T, N have their usual kinetic theory significance. For gases β is the reciprocal of the pressure and μ is almost equal to one, the formula then reduces to Rayleigh formula. The above formula holds also when the size of the density fluctuations is not small in comparison to the wavelength λ. Since the scattering considered is associated with the ordinary refractivity of the liquid, the light scattered at right angles will be completely polarized, The strength of scattering is proportional to T, except that β and μ may also depend on T.

Raman then describes his experimental work on the scattering of light by water. Even a casual glance through this section convinces the reader of his capacity to observe the minutest detail and his determination to obtain a result uncontaminated by any spurious effects. The measurement itself is done by comparing the scattering from water with that from saturated ether vapour—a substance which was investigated earlier by Rayleigh. One is struck by the simplicity of the technique and its sensitivity. The "black cage" background renders even the faintest trace to be visible and the inherent sensitivity of the eye in comparing intensities of two adjacent areas permits an accurate result. His final result is a scattering strength of about 175 times that of dust free air while the theory gives a value of 160. The polarization of the scattered beam was found to be strong but not complete. But Raman is not sure of the molecular origin of this effect in view of the small amount of particulate impurities still present in the water sample. The absorption coefficient is also measured in a region of the spectrum far removed from any selective absorption and the result provided further support for the theory.

Raman then goes on to calculate the luminosity of deep water (e. g. sea) when illuminated by the sun high in the sky (vertical incidence) and as viewed also vertically as from an aeroplane; for example, using the attenuation coefficients for different wavelengths either from earlier measurements or as calculated from the theory. He observes that the light as viewed has a saturated blue colour because of the superposition of the strong $1/\lambda^4$ blue scattering and the larger absorption of the red, orange and yellow parts of the spectrum.

It is only after he has convinced himself of the truth of the Einstein Smoluchowski theory of molecular scattering of light by water that Raman returns to his original problem—the colour of the sea. The theory yields the unavoidable result that the deep ocean water illuminated by the sun will have a more saturated blue colour than that of the sky and it will be almost as intense (if not more) unless the transparency is much reduced due to some extraneous reasons. The clear transparent nature of the deep sea water—unruffled by waves was well established upto depths exceeding several hundred feet.

It will be appropriate now to quote Lord Rayleigh on the problem of the colour of the sea (Raman quotes this in two parts).

"We must bear in mind that the absorption or proper colour of water can not manifest itself unless the light traverses a sufficient depth before reaching the eye. In the ocean the depth is, of course, adequate to develop the colour, but if the water, is clear, there is often nothing to send the light back to the observer. Under these circumstances the proper colour can not be seen. The much admired dark blue of the deep sea has nothing to do with the colour of the water. but is simply the blue of the sky seen by reflection. When the heavens are overcast the water looks grey and leaden, and even when the clouding is partial, the sea appears grey under the clouds, though elsewhere it may show colour . . . One circumstance that may raise doubts is that the blue of the deep sea looks purer and fuller than that of the sky. I think the explanation is that we are apt to make comparison with that part of the sky, which lies near the horizon, whereas the best blue comes from near the zenith. In fact, when the water is smooth and the angle of observation such as to reflect the low sky, the apparent blue of the water is much deteriorated. Under these circumstances a rippling due to wind greatly enhances the colour by reflecting light from higher up. Seen from the deck of a steamer, these parts of the waves which slope towards the observer show the best colour for a like reason."

Raman then proceeds systematically to demolish this interpretation, According to him the presence of the clouds in the sky affects the appearance of the sea in two different ways. First and foremost clouds in the sky reduce the total incident light on the sea surface thereby making the sea look darker than otherwise. Secondly a cloud is seen in the sky against the background of the more brighter portions of the sky and this brighter background causes a brighter reflection making it difficult to see the real colour of the sea water. Having disposed of one part of Rayleigh's thesis Raman moves on to the other part namely the difference in colour seen when the sea is calm and when the sea is ruffled. The difference is very clear Raman argues that for light from inside the sea to be seen by an observer looking at a distant clear portion of the sea, the angle of incidence inside the sea would be almost approaching the critical angle. Since at this angle a large fraction of the incident light is reflected back only a small part of the light comes out. The brightness is reduced further because a narrow incident pencil becomes a rather open cone after refraction. The two effects acting together permit only a very small portion of the deep sea light to reach the observer's eye, while at the same time the light specularly reflected (by the sea surface) so as to reach him is quite strong both because the opposite low sky is bright and the reflection at this angle is almost total. It is therefore, natural that the light from inside the sea which carries the proper colour of sea water is swamped by the reflected light.. As soon as there is a small breeze causing ripples to appear on the surface of the sea a much larger portion of the light incident from below the surface becomes able to reach the observer's eye, there by increasing the proportion of light bearing the true colour of water. At the same time only the reflection from the higher reaches of the sky (nearer zenith) reach his eye so that the reflected intensity is small. Of course when one views the surface vertically downwards the reflection is much smaller because for normal incidence reflectivity of water is very very small (hardly 2 percent) and it is obvious that the colour of the sea would be best seen in these circumstances. This observation was already noted by Tyndall and Buchmann. Even the assertion that reflected sky light augments the colour of the sea significantly is repugnant to Raman and he reserves his most telling argument for the invalidation of this statement.

It was already known that when light is scattered in a direction at right angles to the incident direction by gas molecules. it is strongly polarised. Also it was well known that reflection by a plane surface polarizes the light–the polarization becoming complete if the angle of incidence is equal to the polarizing angle. Such reflected radiation can be easily eliminated by using a polarizer near the eye and orienting it in a suitable direction. Raman as already mentioned in connection with an earlier paper[10] had looked at the sea through a nicol and he had already observed that when the analysing nicol was so oriented as to cutout the polarized reflected beam, the colour of the sea looked a more saturated and bright blue. He also noticed that the light from deep sea also shows a polarization.

Three more notes [15,16,17] in Nature were submitted during the last days of 1921 from Raman's work. In the first[15] one of these submitted on Nov. 19, 1921, Raman conjectures that thermal vibrations in crystals, so well established by Debye's theory of specific heat would introduce fluctuations in the refractive index and this would cause scattering of light. In fact scattering of light by crystalline media was already observed by Rayleigh among other people but he had ascribed it to impurities and imperfections inside the material rather than to any inherent property of the solid. Raman focussed a beam of sunlight into a block of crystal quartz and observed visually a well marked track of scattered ·blue' light. He interpreted it on the same basis as already done for liquids.

The second paper [16] dealt with the imperfect polarization of light scattered at right angles to the incident direction–again a phenomenon which was known earlier and correctly interpreted at least for gases as being due to the anisotropy of the molecules. This short paper is of interest, mainly because of its exemplification of Raman's attachment to visual observations, before, being, convinced of the reality of any phenomenon, and secondly because of his preference for working with a minimum of equipment. Thus, though it was already known that the observed departure from complete polarization of light scattered at 90^0 by the air molecules is due to the anisotropy (lack of spherical symmetry) of the molecule, and photographic studies had proven this without any iota of doubt for Raman this was not sufficient. He states "In view of the great interest of the phenomenon—it would be worthwhile to attempt direct visual observation and measurement of its magnitudes.' The obstacle to this was, of course, the extremely feeble intensity of the scattered light and again it was overcome by Raman's ingenuity. Use of the brightest source of incident radiation, the sun, would, of course, occur to every one, but Raman paid equal, if not more, attention to the creation of a perfectly dark background, to prevention of extraneous light from interfering, and to adapting the eye to low light levels. These precautions worked so well that a student of Raman (Late Dr. K. R. Ramnathan) could easily make quantitative measurements of the polarization. Raman was still not satisfied because the above experiment referred to dust free air in a laboratory environment. He set out to prove that the same holds true in the scattering seen in the sky. He first analysed the factors which would make observation difficult. e. g. direct, reflected light from the earth's surface etc. and then made efforts to reduce these factors. Making observations at red wavelength on a hill in the Nilgiris[16] on a clear winter day he affirmed that there is a residual lack of polarization which can be ascribed to the anisotropy of the molecule. The imperfect polarization of light scattered by liquids as well as transparent solids was also hinted at from observations not described in any detail.

The last paper[17] deals with scattering by glasses and other amorphous solids. The programme of work outlined in this note was carried out subsequently with significant results.

A monograph entitled "Molecular Diffraction of Light" was published[+] by the Calcutta University Press in early 1922. This publication of Raman has as its objective the clarification of the prevailing state of confusion in the literature on molecular scattering of light in solids, liquids, vapours and gases. A study of the monograph is rewarding not only for the brevity and clarity of its presentation but specially in the context of the present paper as it outlines the various experimental and theoretical avenues of work considered by Raman as worthy of pursuit.

He starts as expected with Rayleigh's successful treatment of scattering of light by gases used by the author (Rayleigh) for explaining one of the great natural phenomena "namely the blue colour of the sky." The essential features of this theory are the recognition that individual molecules act as sources of secondary waves and that the waves emitted from different molecules are completely independent of one another so that for finding the net effect the intensities of the various secondary emissions can be added. The resulting equation contains the well known $1/\lambda^4$ dependence of the scattered intensity and the latter is also proportional to $(\mu - 1)^2$ which in the case of gases is proportional to the density of the gas. We have seen that Raman had considered the independence of phases in connection with Larmor's suggestion of the role of the Doppler effect caused by the random thermal motion of the gas molecules. He had shown that phases can be considered random only when the presence or absence of molecules in a small volume does not affect the probability of finding another molecule in the same volume. Another aspect of Rayleigh' treatment of molecular scattering of light which intrigued Raman and in fact formed the subject matter of a number of investigations by him and his group, was the observed imperfection of polarization of transversely scattered light. Rayleigh had measured this imperfection photographically using a carbon arc as the source of light. Raman got this measured by Ramnathan visually using sun light. There was general agreement but also a small deviation which Raman attributed to the difference in the effective wavelengths of the two sources. The cause of the imperfection was of course the optical anisotropy of the molecules of the gas. Raman regarded this aspect of the scattering phenomonon and its expected effect on the strength of scattering so important that he made a trip in the Nilgiri's at that time virgin and unspoilt–to make visual observations on the blue of the sky.[16]

After discussing the scattering of light by gases and vapours-an area in which the Rayleigh theory had achieved a great measure of success, Raman directed his attention to liquids. He starts with the observation made by Lord Rayleigh that his theory is not valid for liquids for the simple reason that molecules in a liquid are much closer to one another as compared to a gas and hence the crucial assumption of independence of phases of secondary emissions from the different molecules could not be regarded as valid. Experimental verification of this statement was provided by Lord Rayleigh who showed that liquid ether scattered light to a much smaller extent than expected theoretically (of course keeping in view the larger density of the liquid.)

Raman considered the Einstein–Smoluchowski treatment of the opalescence of liquids near the critical point and felt that this theory which introduced the concept of fluctuations of mass density in a liquid ought to be applicable to a liquid away from the critical point also. His conjecture met with immediate success as already discussed. A large number of liquids were investigated. The imperfection of polarization of transversely scattered light was investigated and was found to depend on the frequency of the incident light. Raman was always conscious of sources of error in his experiments and greatly emphasised the purification of the liquid under use. He suggests studies with radiation near absorption bands as well as at various temperatures to be undertaken to help understand this phenomenon in greater depth.

Orientation of molecules in a liquid was regarded as very common and was expected to depend on temperature and pressure. The vapours when subjected to high pressure did not scatter as much light as expected on the basis of the Einstein–Smoluchowski theory and it was felt by Raman to require more extensive study. The failure of the "theory of fluctuations" to explain the comparatively weak scattering of CO_2 vapour under high pressure was regarded as very serious. Raman remarked "that the attempt to explain the molecular scattering of light on the basis of the classical theories of electromagnetic wave propagation and the continuous interaction between light and the electrons is really a failure. We may then be forced to adopt explanation based on a discontinuous type of action, exactly as in the theories of photoelectricity, ionization,.........". He also felt that the observation that transversely scattered light from a dense vapour is more perfectly polarized than that scattered from the liquid required some explanation.

Raman considered also scattering of light from crystalline and amorphous solids. For crystalline solids the well established Debye theory of specific heat suggested existence of thermal oscillations of atoms about their mean position and Raman correctly surmised that the consequent fluctuations of the refractive index would cause scattering. Again, the actual scattering had been observed earlier but Rayleigh had dismissed them as caused by inclusions and impurities. Raman applied the same theory of fluctuations corrected empirically for the modification of the law of equipartition of energy and achieved qualitative agreement.

Raman mentions in this monograph that the track of light inside the crystal after illumination by focussed sunlight was visually observed. For a crystal of Iceland Spar the track was having a reddish tinge but this was due "apparently to a feeble fluorescence". This is probably the first reference to a change of wavelength in scattering, i. e. the 'Raman effect'. Again the question of imperfection of polarization was referred to and suggested as a possible candidate for further study. Studies of light scattering by amorphous solids are also referred to.

In the last section of this monograph dealing with quantum theory of radiation and molecular diffraction. Raman makes some comments on the status of the radiation theory. It is very interesting to note Raman observes, "Eienstein's idea of light quanta has apparently been regarded as unnecessarily revolutionary in character". This is characteristic of the working physicists opinion on the quantum theory as has been beautifully and forcefully analysed by Pais[18]. Raman says that the Planck's theory supplemented by the correspondence principle works sufficiently well and is more readily accepted. He however feels that this 'hybrid theory' (emission and absorption in a discrete manner and propagation in a continuous manner) is not philosophically satisfying while the Einstein photon theory is. He predicts that study of light scattering may help in clarifying this situation. We must conclude that despite his firm faith in Maxwell's electromagnetism and theory of radiation, Raman was not averse to the idea that newer phenomena may yet show a departure from the same. This suggestion of Raman was commented upon[10].

The publication of this monograph also marks the end of the early perlod. Many students had by now joined Professor Raman in his investigations and from now onwards a number of publications[20] arise from these students. As stated in the introductory section of this paper our own observations would be mainly limited to papers in which Raman is an author or a co–author.

1922 - 1927 Consolidation Of Experimental And Theoretical Studies :

The year 1922 seems to have been very productive for Raman and his group as a stream of papers have been submitted during this one year on the subject of molecular scattering of light. Moreover, his interest in the scattering of X-rays has also become active specially with a view to understanding the nature of scattering by liquids. This second point is important for two reasons. Firstly this interest in x-ray scattering led to the developments which resulted in Raman's school emerging as one of the leading centres in x-ray structure analysis. Secondly. and of more direct interest to us in this paper, this interest marks the beginning of Raman's afforts to understand x-ray scattering on the same principles as light scattering. We will see towards the end of this article that it was in an attempt to explain the newly observed Compton scattering on the basis of the classical theory that Raman felt the need to look for a change of wavelength in light scattering However, this is still several years in the future and we continue our readings through Raman's papers.

At first we will consider a group of five short papers[21-25] published in Nature during 1922 (in fact one of the papers appeared in

1923) dealing with different aspects of molecular scattering of light in liquids and solids. The first of these papers considers the results of certain experiments conducted by Ramanathan who studied the scattering of light by liquid CO_2 at various temperatures. It is found that the scattering falls off as compared to the theoretical result of Einstein-Smoluchowski theory when the critical temperature is approached (from below). Raman attempts to explain this discrepancy as implying, following Jeans, two distinct types of clustering. The first type of clustering is essentially a mass clustering leading to density fluctuations which are considered in the above theory as the cause of light scattering. In addition there can be a molecular clustering-formation of aggregates which has no effect on mean density but affects light scattering. Since this second type of clustering is expected to be predominant only near the critical point the experimental finding is at least qualitatively explained. Raman however is not satisfied and raises the question why is then mass clustering sufficient, to yield the correct result in a large number of cases when Maxwell's electromagnetic theory is used. He feels that this is a point which, in fact, involved a break down of the wave theory of light and the detailed work on this problem already underway would help clarify the situation. A prophetic statement indeed as the paper is dated March 2,1922 almost exactly six years prior to the discovery of the Raman effect which gave additional proof for the correctness of the quantum theory.

The other papers of this group deal essentially with an elaboration of this two component scattering theory. According to Raman, scattering in all material bodies is of two types-a mass fluctuation scattering described faithfully by Einstein-Smoluchowski theory and secondly a completely molecular (or at least molecular aggregate) scattering which depends directly on the density. The first type of scattering is completely polarized while the second type is completely unpolarized. Since aggregates decrease in going from liquid to vapour the defect in the polarization of transversely scattered light will decrease when we go from liquid to vapour, a result in conformity with experiments. Both pure liquids and liquid mixtures are included in this study. It is also concluded from the measurements of polarization that molecular anisotropy is a function of incident frequency–a result of great significance.

Raman, as we may recall from our previous discussion had already given a very satisfactory explanation of the colour of the sea, absorption by sea water and the 'albedo' of the earth on the basis of the Einstein–Smoluchowski theory. Now that the theoretical basis of explanation of the molecular scattering stood modified Raman returns to the same question and shows that the later theory improves agreement with the experimental findings. In the last paper of this group the observed blue colour of clean glaciers is explained.

The theoretical ideas expressed in the first paper of the above group of papers are developed in detail in a joint paper[26] with Ramanathan. Again Raman mentions his belief that a study of light scattering would shed light on the nature of radiation itself. A general derivation of a scattering formula is given which starts from a non-random distribution of molecules controlled by Boltzmann's distribution function. In a subsequent paper[27] the same authors consider light scattering by liquid mixtures. In contrast to earlier work where only the fluctuation of concentrations were considered as causing scattering the authors show that fluctuations of density would also contribute. The theory is derived in a general form and general agreement with experimental results is achieved.

A more consequential paper is by Raman and Seshagiri Rao in the same volume of the Philosophical Magazine[28] as the above two papers (all three were published in 1923 but resulted from work done in 1922). In this paper in addition to other objectives of such study a new one namely the structure of liquids–is added on. The authors again assert that the condition of random phases for secondary emissions from different molecules is not fulfilled in liquids and hence Rayleigh theory would not hold contrary to the belief expressed by some authors. After outlining the 'theory of fluctuations' due to Einstein & Smoluchowski as the correct theory for liquids they give an explanation for the defect of polarization of scattered light in terms of molecular anisotropy. Assuming random orientation of the different molecules they obtain a justification for the Cabannes factor by which the intensity of the scattered light is increased if anisotropy is accounted for. The authors conclude from their measurements on a large number of liquids that the ratio of the intensity of the unpolarized weaker component to the intensity of the stronger polarized component changes significantly with the wavelength of the incident light. A significant observation in this context is the following" This (dependence of depolarization on λ) is no doubt the explanation of the fact that the tracks of the primary beam in different liquids do not exactly match each other even when the intensities are equalized by altering the aperture".

It is clear that upto this point of time (June 1922) there was not even a hint of a change of wavelength on scattering-even though tracks of different colours are seen in different liquids. Study of the temperature dependence of the depolarization indicated that the assumption of completely random orientation of the anisotropic molecules is not true. A method for determining the Avagadro's number from such studies is mentioned. Complete details of the method used to measure the polarization characteristics of light scattered by gases and vapours is described in another paper[29] with Seshagiri Rao. A detailed report of the study of CO_2 under high pressure is given in a paper[30] with K. R. Ramanathan.

Raman was not the only one interested in scattering of light by anisotropic molecules and Raman wrote out a paper[31] in Nature criticising one by King[32]. A short paper[33] sent from on boardship Kaiser-i-Hind and published in 1924 in Nature is interesting because it attempts a correlation between the optical anisotropy as measured by light scattering and the structure of molecules. While the actual explanation given by Raman has lost in importance, this study is the progenitor of an extensive amount of work by Raman & Krishnan during the next few years which attempted to relate optical anisotropy, electrical and magnetic anisotropy, birefringence and molecular structure. Light scattering from liquid and solid surfaces was also investigated[34], several papers[35-37] relating the observations with the surface tension also appeared.

We will now start our study of the papers dealing with the scattering of X-rays by liquids. The earliest paper[38] in this connection was submitted to Nature in early 1923. During the previous year diffraction rings had been observed when monochromatic X-rays were scattered by ordinary liquids. Several conjectures like postulating the existence of crystallites or special aggregates had been suggested in the literature. Raman as we have noted at several points earlier was not interested in inventing special hypotheses for explaining special results. He boldly suggests that the Einstein-Smoluchowski idea of fluctuations ought to be able to explain these observations also. Another somewhat earlier paper[39] in Nature dealing with the nature of the liquid state suggests that some sort of aggregation of the liquid molecules may lead to an improvement between theory and experiment.

A more substantive paper[40] on this topic is in joint authorship with Ramanathan published in the Bulletin of Indian Association for the Cultivation of Science in early 1923. In this paper the authors extend the theory of fluctuations, by removing one of its most important limitations. In the original form of the theory the liquid is considered as a continuum with no graininess-an assumption which is well justified as long as the mean molecular separations are very small as compared to the wavelength of the radiation. This is, of course. no longer true for the X-rays that were used in the liquid diffraction experiments. Raman and Ramanathan by an ingenous technique of considering the liquid sample to be divided into small rectangular slices which contain many molecules rederived the Einstein-Smoluchowski scattering formula for visible light. They show that if slices of width $\lambda/2 \text{ Sin } \frac{1}{2}\theta$ contain many molecules the condition of random phases can be satisfied and the usual scattering formula would hold. For X-rays because of their small wavelength this condition is not fulfilled unless θ is very small. For large values of θ these slices will contain very few molecules and hence fluctuations in the number of molecules in the neighbouring slices would be highly correlated. For example, if the slices are so small as to contain only one molecule on an average then if one slice contains an excess molecule the slices enclosing this particular slice on the two sides are most likely to contain a deficiency of one molecule. Because of this strong correlation, in the fluctuations most often the secondary emissions will annihilate one another unless a certain angle is reached when the phases will favour a strengthening. This is the reason of the halo seen around the primary beam. During the next 2-3 years the main emphasis of Raman's group seemed to be the study of electrical and magnetic properties of materials (mostly liquids). Birefringence of crystalline materials and their relation to structure. Kerr effect, magnetic double refraction etc. all were investigated in detail.[41] K. S. Krishnan was the main coworker of Raman during these studies and their names appear together in a whole series of papers. Experimental studies were supplemented with theoretical investigations and all along the question of molecular anisotropy of molecules as revealed by polarization studies on light scattering formed one of the important ingredients. An important compilation by Krishnan appeared[42] in 1925 where in light scattering by 65 pure liquids was investigated. In many cases there was an indication of scattered light containing radiation of a wavelength different from the incident one. Since this paper is one of the papers cited by Raman in his reply[2] to Darwin's article it may be some what intereating to see what Krishnan writes about his results.

The objective of this paper was to provide "a more comprehensive experimental work...in order to determine more clearly the influence of the molecular constitution of the liquid." For this purpose "intensity and depolarization for different regions of the spectrum of light scattered by about 65 liquids were measured. In the case of a number of liquids, the imperfection of polarization was measured also for different parts of the spectrum using for the purpose coloured filters." Whenever any wavelength dependence of the depolarization was found–a method used by Ramanathan for testing for the presence of fluorescence was used. The method consisted in transferring the coloured filter from the incident beam to the scattered beam and remeasuring the depolarization. Any change from initial value was taken as evidence of fluorescence. Blue and orange filters were commonly used in this study but sometimes a green filter was also used.

The explanation of the change of depolarization when the coloured filter is transferred to the scattered beam is as follows. Suppose, blue light excites a green fluorescence, then when blue filter is in the incident beam, "the scattered light would be mixed up with the fluorescent light, and if we assume, as we may reasonably, that the fluorescent light is mostly unpolarized, the light observed would show an abnormal imperfection of polarization. On transferring the blue filter to the scattered beam, however, the imperfection would become normal. If instead of a blue filter, we use a green filter, normal polarization would be observed when the filter is in the path of the incident beam and an abnormally high polarization when in the path of the scattered beam". Applying this test Krishnan concluded that in all those cases where the depolarization is affected by changing the position of the colour filter(from incident to scattered beam) there is "a feeble fluorescence" and in all cases "the exciting region is at the blue end of the spectrum, the excited region coming much lower down including to an appreciable extent the orange". Krishnan argues further that it is not likely that orange light would excite any fluorescence and hence the depolarization measured with this incident light can be taken as a standard to which the other values are to be compared. Comparing this value with the value obtained for blue incident light Krishnan alludes to two possibilities as an explanation for the higher value in the latter case. The two possibilities are (i) there is a certain fluorescence excited by the violet light and (ii) the blue light for some reason gives a higher depolarization. He favours the second alternative as more plausible.

Krishnan goes on to discuss the weak intensity of this feeble fluorescence and its relation to the ordinary fluorescence. Assuming that the fluorescence is entirely independent of scattering and is merely superposed over the former, he finds that the feeble fluorescence has an intensity about 0.04 times (for ether), 0.01 times (for methylalcohol) and 0.80 (for benzalchloride) of the transversely scattered intensity.

In a related development Raman and Krishnan [43],[44] extended and modified the Born-Langevin theory of electric and magnetic birefringence. It was observed that if molecular anisotropy of a molecule is calculated on the basis of this theory from experimental measurements in the vapour and in the liquid phase two appreciably different values were obtained. This effect was reminiscent of the similar conclusion while light scattering from liquids and vapours was investigated. This difference had been attributed to orientational effect and it was natural to consider this contribution in a more rigorous manner. Raman and Krishnan argued that the failure of the Born-Langevin theory is due to an assumption in the latter that even though the individual molecules have an anisotropy the polarization field induced by the applied field retains a spherical symmetry which justifies the use of Lorentz-Mossotti relation. This assumption when removed led to a small modification of the formula and removed the discrepancy referred to earlier. It was natural for Raman to consider the effect of this modification on the properties of light scattered from asymmetric molecules e. g. intensity and depolarization. The birefringence in liquids introduced due to viscous flow-the socalled Maxwell effect was also explained [45] by the same theory.

In a comprehensive study [46] of light scattering from amorphous solids the results from which were summarized by Raman in a communication to the Optical Society of America- 14 different optical glasses were investigated for their light scattering characteristics. The results substantiate largely the molecular scattering hypothesis involving both density fluctuations and orientational effects as described successfully for liquids. It is found that the scattered intensity is more for the highly refracting glasses while the depolarization is larger for the less refracting crown glasses. In the latter cases the colour of the scattered light is often very different from the expected blue, in some cases being seen as pink or orange.

Raman states "The colours shown by the fainter component of the scattered light......are obviously due to a species of weak fluorescence, probably of the same kind as has been met with in investigations on light scattering in liquids. This fluorescence being unpolarized the large values of the depolarization found in the case of these glasses stands self explained. It is interesting to notice that (in some cases) we have a low value for the depolarization inspite of the obvious presence of a weak fluorescnece.....", This paper was submitted in May 1927 and it is obvious that contrary to the implication in Raman's reply to Darwin, he and his colleagues had dismissed this change of colour as a weak fluorescence which is completely unpolarized and has the disturbing influence of denigrating the state of polarization of the scattered light. The last part of the above quotation however, does indicate that there was some reason to doubt this facile explanation.

The work on X-ray diffraction by liquids which was somewhat dormant seems to have been revived in 1926-27 as is evident from three publications in Nature in 1927 with Sogani[47-49]. In the first two papers qualitative changes in the intensity and sharpness of the X-ray haloes observed in going from one liquid to another are noted and are attributed to molecular structure changes. In the third paper the degradation of the haloes as the temperature of the scattering liquid is raised are noted- The observations are explained in terms of the theory given earlier by Raman and Ramanathan[40].

The Discovery

This renewed interest in X-ray scattering and his involvement with an understanding of the Compton effect seems to have been influenced by the visit of Professor A.H. Compton in 1926. Compton had come to India on a sabbatical leave for one year to the Foreman Christian College where his brother-in-law was a professor of physics. Compton measured cosmic ray intensity at Gulmarg and had asked Raman for some gold for his electroscopes. Any account of the discussions between the two giants of science would have been really illuminating. I am not aware if a record exists.

The paper [50] in Nature entitled "Thermodynamics, Kinetic Theory and the Compton Effect" was submitted on Nov. 10,1927 and printed the same year. This for the first time reveals Raman's attempts to understand the Compton effect on the basis of the classical electromagnetic theory as he had successfully done for light scattering in liquids, gases and solids. Raman highlights the incogruity of Compton's explanation of his effect with the well established wave nature of light in the following words. "This view of the Compton effect, like Einstein's explanation of the emission of photo electrons, approaches the relation between matter and radiation from a point of view so divergent from the familiar concept of Maxwellian electrodynamices, that it is scarcely possible to understand how this conception of radiation is physically reconcilable with the familiar explanations of interference and diffraction phenomena".

Compton had explained that the unmodified line is a consequence of scattering of the incident baem by all the Z electrons present in an atom taken together. This did not seem consistent to Raman who queries—"That if one electron acting alone can scatter a quantum, and also all the Z electrons in the atom acting together, why then we do not observe scattering by two, three or more electrons acting together at a time with the corresponding fractional Compton shifts in wavelengths ?" An alternative explanation of the unmodified line as being due to scattering of an electron which 'the impinging radiation is not able to detach from the atom' does not satisfy Raman who asks "why is the intensity of this type of (scattering) radiation proportional to Z^2 and not to Z ?"

In addition to the above objections to Compton's explanation Raman cites a more fundamental one for which he refers to his Toronto address to the British Association in Aug. 1924. Speaking on the scattering of radiation by materials he cites the successful application of Maxwell's theory coupled to thermodynamical reasoning for explaining the observed scattering of visible light by liquids, vapours and solids. He then asks the question "Is it concievable then, that Maxwell's theory and thermodynamics taken together would fail in this closely, allied field of research ?" His own answer to this question is No, and he outlines an explanation for the X-ray diffraction haloes in liquids.

Raman then goes on to briefly outline the basic ideas of his theory (details of which appeared in Indian Journal of Physics, see below) which in his opinion not only explain Compton's observations but also those of Bothe and Geiger and of Compton and Simon which at first sight seems so destructive of classical wave ideas." Raman's basic premise in this classical explanation of the Compton effect is that thermal agitation not only moves the atoms about their equilibrium positions but can cause atomic electrons also to be excited from their equilibrium state. Two possible sources of scattering of radiation by atomic electrons are then possible. The first type of scattering is caused while the electrons remain in their equilibrium state and all of them coherently produce a diffracted beam, no change of wavelength is expected in such scattering. The second type of scattering is caused due to the fluctuations in the electronic state and in this case since each electron changes its state in a random fashion (not in coherence with other electrons) statistical considerations have to be included in its calculation. These two types of scattering are to be associated with the unmodified and the 'modified' Compton scattering.

It is clear that if thermal agitation is the cause of the fluctuations resulting in Compton scattering the intensity and shift may both depend on temperature. Even though no direct evidence was forthcoming Raman felt that the argumentation is basically sound. It is interesting to note however, that Raman as yet did not mention if a similar effect should be present in light scattering.

The paper [51] in Indian Journal of Physics already referred to in the above mentioned paper does not mention the date of submission however it is apparent that it was almost simultaneous with the previous paper. Raman assumes a model for the atom in which in the ground state of the atom the electrons are confined to a certain volume but in this volume they are distributed in a manner similar to the molecules of an ideal gas (Kinetic theory description). When an-X-ray beam is incident on the atom all the electrons serve as sources of secondary waves and it is the net result of all these secondary waves which gives us the scattered radiation. The phases of these secondary waves differ from one another and depend on the mutual separation between the electrons as well as the geometrical arrangement of the scattering set up. Summing up the amplitudes of the various secondary waves and then obtaining the intensity of the scattered radiation one obtains two distinct distributions. The first term in the intensity is found to be proportional to Z^2 and Raman interpreted it as the diffraction due to the whole atom. The second term is proportional to Z and is to be distinguished from the Thomson scattering and to be identified with the Compton scattering.

The change in wavelength is interpreted as a consequence of the Doppler effect caused by the action of the electromagnetic momentum. The 'fluctuations' in the electronic distribution is clearly considered as different from the 'thermal fluctuations' considered earlier by Raman and his coworkers.

Raman is aware of the 'adhoc' nature of his atom model but feels that any improvement in this aspect would still retain the essential two term nature of the scattered intensity. Again nomention of any similar effect to be expected in light scattering appears in this paper.

We now come to the fateful year of 1928. In the February of that year Raman and Krishnan submitted a note [52] entitled 'A new type of Secondary Radiation' which may be regarded as the first announcement of the Raman effect even though Raman himself in his address to the South Indian Science Association mentions Feb. 28 as the date of the discovery. The paper for the first time reveals the influence which Raman's efforts to explain Compton effect on classical basis had on his understanding of light scattering. In the first sentence of this paper the authors write "If we assume that the X-ray scattering of the unmodified type observed by professor Compton corresponds to the normal or average state of the atoms and molecules while the modified scattering of altered wavelength corresponds to their fluctuations from that state, it would follow that we should expect also in the case of ordinary light two types of scattering, one determined by the normal optical properties of atoms or molecules, and another representing the effect of their fluctuations from their normal state."

They report that they see this modified scattering at altered wavelengths in almost all cases, using sun light focussed by a large telescope objective as the source and complementary filters to detect the change of wavelength. It is surprising that the authors do not refer to the earlier papers by Krishnan [42] and by Raman[40] in which presence of a changed wavelength in the scattered light was noted but attributed to a 'feeble fluorescence'. They conclude "That the effect is a true scattering and not a fluorescence is indicated in the first place by its feebleness in comparison with ordinary scattering and secondly by its polarization which is in many cases quite strong and comparable with the polarization of the ordinary scattering".

A later note[53] in Nature by Raman was submitted on March 8, 1928 entitled 'A change of wavelength in light scattering'. The sun has been replaced as a source of incident light by a Hg-arc from which all other radiations except those shorter than 4358A^{0} are removed by filters. One sees some sharp lines (overlaid by a continuum) which are shifted towards the red of the incident wavelength.

Raman delivered a lecture[54] at Bangalore on Friday March 15, 1928 to the South Indian Science Association in which the discovery of the effect was announced to the public. A history of the efforts leading to this discovery were given. The persistence of the socalled 'weak fluorescance' as observed right from 1923 is mentioned and his own misgivings about this facile explanation. An interesting observation by Raman clarifies why this was not published as an independent effect. He states that the publication was deferred due to "the belief then entertained that only a few liquids exhibited this effect and by the supposition that it was unpolarized in the same way as ordinary fluorescence in liquids". He goes on to state.

"........a powerful impetus to further research was provided when I conceived the idea that the effect was some kind of optical analogue to the type of X-ray scattering discovered by Prof. Compton......"

Raman also mentions a study by Venkateswaran in Jan. 1928 in which he found that for glycerine the scattered radiation at a changed wavelength is strongly polarized, a result Raman calls "amazing".

An explanation of the observed effect in terms of the Kramers Heisenberg dispersion theory is given and the existence of a modified line with frequency larger than that of incident light is also referred to.

Following this acceptance of the altered wavelength seen in the scattered beam as a new phenomenon a spurt of activity took place and there were several papers[55-58] in Nature during 1928 reporting on one or the other aspect of the new effect. Two detailed papers [59] one in Indian Journal of Physics and another[60] in the Proceedings of the Royal Society also appeared. A broad survey was given and the role of the effect in the study of molecular spectra in the infrared as well as its relation to structure were emphasized. These however fall outside the purview of the present effort.

I wish to conclude this paper by referring to Ramans' reply[2] to the observations made by C. G. Darwin[1] in which he correctly asserts that the work of the Russian workers was published only after 16 papers had been published from Raman's group. The paper also cites the five important characteristics of the effect.

In a lecture[61] to the Faraday Society in 1929 Raman stated "As explained in my written paper, its discovery was no accident but was the result of systematic research on the subject of the molecular scattering of light continued for several years in the hope that results of a fundamental character would be reached." Identifying the cause of their persistence in this study Raman stated "It was in the attempt to investigate experimentally how the optical anisotropy of molecules varied with wavelength of the incident radiations that we were led at Calcutta to the discovery of the existence of scattered radiation with altered wavelength." Similar observations were made by him in his Nobel lecture[0]. CONCLUSIONS:

This survey of Raman's papers on the molecular scattering of light clearly establishes the truth of the observations made by Raman at the Faraday Society lecture. The crucial ingredient of the discovery is established as the effort to interpret compton effect on the basis of the classical theory.

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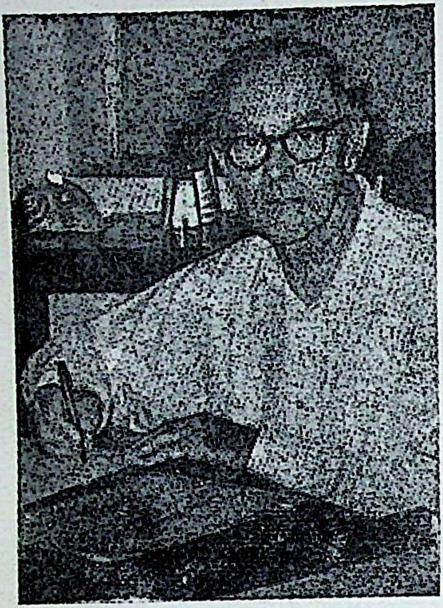

G. W. SERIES

Raman Professor, 1982-83

Prof. Series was born on 22 February, 1920 and received his B. A., M. A. and D Phil from Oxford University, where he worked on the spectrum of atomic hydrogen for his thesis. Cooling the discharge tube with liquid hydrogen, he was able to provide an optical determination of the Lamb shift both in hydrogen and in singly ionised helium. After the discovery of the double resonance technique he applied it to an excited state of potassium and determined the electric quadrupole moment of the nucleus. Prof, Series pioneered the now widely used technique of optical quantum beats, demonstrating coherence between Zeeman transitions which are at different frequencies because of an imposed magnetic field. This work brought into focus the alignment tensor describing the state of a three-level system, and gave rise to the picture of an atomic vapour acting as an anisotropic medium, while undergoing optical-radio frequency double resonance. Another result was that one could reduce the natural width of a transition by biasing the observation in favour of those atoms which survived over many spontaneous lifetimes.

After 1968, Prof. Series's interests turned to the basic nature of spontaneous emission as the key difference between the semiclassical and the quantum pictures of light. Simultaneously he has been active in laser spectroscopy and the study of optogalvanic effects.

In 1982, Prof. Series retired from the University of Reading and visited India as the Raman Professor of the Indian Academy of Sciences.

OPTICAL PUMPING, RESONANCE FLUORESCENCE AND RAMAN SCATTERING

G. W. SERIES
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The essence of the Raman effect is this: that in the scattering of light by matter, the characteristics of the matter may impress themselves upon the light, so that a comparison of the scattered light with the incident light allows properties of the matter to be deduced. Most often, attention is concentrated on the *frequencies* of the incident and scattered light: if there is difference, this is attributed to some characteristic periodic motion in the matter which, superimposed upon the periodic motion of elactrons induced by the light falling upon them, results in a modification of their periodic motion and hence of that of the radiation which we see as scattered light.

It was such a change which led Raman to the discovery of the effect which bears his name. The deep blue colour of the Mediterranean sea, was, as he became aware, not the same as that of the light falling on it. Systematic, painstaking studies back in Calcutta revealed very faint spectral lines in the light scattered from liquids whose frequency was different from that of the light which irradiated them. The effect was weak for two reasons: the first, that the interaction of light with matter is, in general, a weak effect—else we should all be blown to pieces as soon as we came out of the dark: the second, that it was, in this case, non-resonant. The frequency of the incident light did not match any characteristic frequency in the liquids Raman used, nor did that of the scattered light: only the *difference* in frequencies was characteristic of the molecular motions.

One can still speak of Raman scattering when the interaction is resonant, though in this case the resonant nature of the process is generally emphasised in the name: resonant scattering, or resonance fluorescence.

The resonance fluorescence of sodium vapour is a well-known example. When light from a sodium lamp is used to irradiate a vapour of sodium atoms, the path of the light through the vapour shows up as a yellow glow, like a searchlight beam shining through fog. It is still a two-step process, as is the non-resonant Raman effect. The light excites the atoms (or molecules) and they decay by spontaneous emission. It is important to realise this. We are not talking of lasers and the *stimulated* emission that is essential to laser action. Raman scattering and resonance fluorescence were studied and interpreted long before lasers were invented. The light scattered by atoms and molecules in the *linear* Raman effect and in *linear* resonance fluorescence (intensity of scattered light *linearly* proportional to intensity of the incident light) comes through the mechanism of *spontaneous* emission, an isotropic perturbation, always present, and attributed in conventional quantum theory to the all-pervading zero-point fluctuations of the electromagnetic field. The light excites the atoms: the zero-point fluctuations de-excite them, resulting in re-radiation of light.

Now let us go back to resonance fluorescence, and keep sodium atoms in mind as our example. Owing to the properties of their nuclei-not simply point charges, but, additionally, magnetic dipoles—sodium atoms possess hyperfine structure. Characteristic frequencies are associated with the motion of the nuclei relative to the electrons. And now we see how Raman scattering may operate in sodium resonance fluorescence: although the frequency of the incident light is in resonance with electronic motions in the atom (resonant scattering), yet the frequency of the re-radiated light may differ from that of the incident light by a very small amount-one of the frequencies characteristic of the nuclear motions, a hyperfine structure frequency.

All this time we have spoken of *difference of frequency* as characteristic of the Raman effect. But that is not the only way in which the properties of the scattering material may impress themselves upon the scattered light. It is well known that the scattering process may change the *polarization* of the light. This has nothing to do with frequency: it is a question of the direction of oscillation of the electric

(and magnetic) fields as the light travels. Of course, the scattered light may radiate out from the scattering material over a wide range of angles (not, strictly, in *all* directions) and if the material has isotropic scattering characteristics, the electric field oscillations of the scattered light will be parallel to those of the incident light, though the direction of travel may be different. But the scattered light is sometimes *depolarized:* the electric field oscillations have been twisted in some way, and for the underlying cause we must look for some twist or skewness (anisotropy) in the scattering material itself. So, again, this is a true Raman effect. Whether or not there has been a change of frequency, if the scattered light is depolarized, it is telling us something important about the scattering material.

And now we have prepared the ground to talk about *optical pumping*. invented by Kastler in 1950 and rewarded with a Nobel prize in 1966. It is a phenomenon complementary to the Raman effect, and it is fitting that the discoverers of both effects should have been accorded the highest distinction which can be bestowed upon scientists. In his Nobel lecture, Kastler recalls the seeds from which his discovery grew: the depolarization of light in Raman scattering is one of them.

So what is *optical pumping*, and in what sense is it complementary to the Raman effect ? In this sense, that in Raman scattering attention is focussed on the changes brought about in light through its interaction with matter. In optical pumping attention is focussed on the changes brought about in matter through its interaction with light. And since we want to make the process as efficient as possible, we use the *resonant* interaction; sodium vapour irradiated by sodium light, for example.

In its first expositions, optical pumping was described in terms of the orientation of atoms. Attention was concentrated on the orientation of the electron clouds. Sodium will still serve as an example, but we need no longer think about the atomic nuclei and hyperfine structure. Of course, the atomic nuclei are *there*; we can't ignore them when we come to work out the details. But to establish the principles it is sufficient to concentrate on the electronic structure of atoms, and in the case of sodium (chemically monovalent) we need only think about one electron, the most loosely bound. It has *spin;* it is a little magnet which spins about its own axis, as well as being electrically charged. And its properties, recognised and described by quantum theory, are such that if you attempt to determine in which direction the spinning magnet is pointing, you can get *one of two* possible answers, not more. Now, when light shines on the atom, the direction of propagation of the light gives you a reference direction against which to check which way the electron is pointing, forwards or backwards. Moreover, suppose the light is circularly polarized (that means that the electric field rotates as the light travels forward). *the interaction with the atom will depend on whether the light field is rotating in the same sense as the electron or opposite to it.*

See, then, what happens when circularly polarized resonance radiation is directed upon a sodium atom. Either it interacts or it doesn't, depending on which way the electron is pointing. Suppose the interaction is with the backward-pointing ones but not with the forward-pointing ones. Then, after the interaction the electron's direction *either* won't have changed at all (if it was originally forward-pointing) *or* it *may* have changed(if it was originally backward–pointing)–and, of course, if it has changed, the scattered light will have been depolarized. Taking the average of a large number of interactions, *some* of the atoms will have been turned over by the light: after the interaction they will be pointing forwards, whereas originally they had been pointing backwards. And as for those originally pointing forwards, none of them will have been turned over by the light. So, for an assembly of atoms originally in random directions (equal numbers pointing forwards and backwards), the net effect of the interaction with circularly polarized light will have been to create an imbalance in the numbers pointing forwards and backwards.

What does this mean ? An atomic vapour in which the atoms are elementary magnets, originally pointing in random directions, is an unmagnetized vapour. But if there is an imbalance in the number pointing forwards and backwards, then we have created a macroscopic magnet. We have magnetized the vapour simply by shining light onto it. This is optical pumping. But we have also changed the light. This is the Raman effect.

This is not the place to elaborate on the scientific successes of optical pumping. It has found applications in pure science (determination of magnetic properties of atoms and atomic nuclei) and in applied science (exceedingly sensitive magnetometers), but above all it stands, together with the Raman effect, as an example of the subtleties of the interaction of light and matter. Books have been written in amplification of this thesis. If any interested reader has access to a recent publication of the Indian Academy of Sciences (Bangalore 1985) entitled 'Laser Spectroscopy and Other Topics, under the authorship of the present writer, he will find a number of review articles bearing on optical pumping and references there to more detailed treatments.

Meanwhile, to conclude this brief essay, I wish to thank Professor Rai for having given me this opportunity to bring out the connection between these important branches of physical science and the effect discovered by C. V. Raman, the centenary of whose birth we celebrate this year not only in India, but in all other countries where great scientists are held in high regard.

SOME PERSONAL REFLECTIONS ON SIR C. V. RAMAN, F. R. S , NOBEL LAUREATE

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I had the greatest good fortune to be closely associated with Prof. Sir C. V. Raman for eleven years (from Nov. 1949 to Oct. 1960) from the very beginnings of the Raman Research Institute, an Institution created by Raman for pursuing his scientific interests, after retirement from the Indian Institute of Science. I began my scientific career with him as a research assistant and won his confidence and affection. He was extraordinarily kind to me and shared his scientific and other interests without any reserve.

Raman was a true scientist and lived all his life as an active researcher. In his scientific career he pursued his research interests with great vigour and set for himself highest-standards and goals. His immense curiosity for understanding natural phenomena, power of observation and persistence led him to make one of the greatest discoveries in physics namely "The Raman-effect". C. J. Davisson another Nobel Laureate who was associated with the Bell Laboratories in the early days wrote an article in 1930 on Sir. C. V. Raman's discovery and had this to say. "It was remarked earlier in that the Raman experiment is a rather simple one which might have been made with equipment available in any physical Laboratory at any time in recent decades. It was no accident, however, that this particular discovery was made by Raman rather than someone else. Important discoveries in physics, even quite simple ones, are usually made only by investigators who have cultivated intensively the particular field concerned, and this is strikingly true in the present instance." In the same article Davisson comments "It-speaks well for the development of science in India that Professor Raman apparently owes little or nothing of his eminence to direct contact with physicists in other countries. His formal training was received entirely in India, and, except for a single year, he has worked only in his native land." Raman was a native genius who put India on the scientific map, by his own efforts.

Raman was a towering scientific leader and trained a large number of scientists in India to assume leadership in the field. During his tenure at the Indian Institute of Science in Bangalore, scores of students passed through his Laboratory where they learned scientific methods of thinking, and methodology of scientific research. Raman was a source of tremendous inspiration for the young minds and he kindled their creativity and true interest in Science. He gave them interesting problems, often worked with them in understanding their results, and developed their analytical thinking and skills. Prof. Raman's Indian Institute of Science days were one of intense involvement with students and their scientific activity. During his tenure there (1933–1948) he was not altogether a happy person because of certain unpleasant incidents connected with his office as the Director. He gave up the Directorship and continued as Professor of Physics until his retirement in 1948. In fact the urge in him to create a private Institute was born out of the frustrations that he had to endure during his stay at the I. I. Sc.

Raman was a relaxed scientist when he moved into his own Institute, but his scientific interests were always as intense and passionate. He valued intellectual freedom and hated all bureaucratic practices. When a prominent politician spoke of scientists engaged in basic research as people who sit in ivory tower and do not contribute anything of practical value, Raman said "Sir, the people who sit in the ivory tower are the only ones who matter. They are the salt of the earth and without them there can be no scientific progress." Raman retired from the Indian Institute of Science in 1948 but he never retired from science. He was always active pursuing some scientific problem, with great enthusiasm and seriousness. He adored Nature and loved meeting people and talk to them,

Raman and His Institute

During the Raman Institute era Raman's attitude towards science, personalities and life had three phases: (1) a phase in which he exhibited tremendous enthusiasm and joy in seeing his dream of creating his own Institute coming true (2) pursuit of science to satisfy an inner aesthetic sense for color, order and beauty in Nature, in which he totally immersed himself (3) a period marked by discontentment and perhaps withdrawal. The first and second phase had quite a bit of overlap and I saw Raman at his best during these phases. Unfortunately, these two phases were punctuated by several unpleasant episodes, which caused him much unhappiness.

Between the years 1950–1960 Raman carried out a number of studies on gems and minerals and he enjoyed this very much. He published a series of papers on the structure and optical behavior of gemstones, mostly with me as a collaborator, and these contributions represent a body of work in which Raman's taste for aesthetics in physics comes through. He used to sit for hours in a darkened room, with a beam of sunlight to probe the optical phenomena exhibited by gems, and come out with illuminating findings. Whether it is the luminescence of diamonds, the multicolored spectrum of opal, the labradorescence of feldspars, or the schiller effect in moonstones Raman's wonder and amazement knew no bounds. Raman thought loudly when making observations and this was an unforgettable experience to listen to. These experiments, simple though in their make up, reflected Raman's deep understanding of optics. He enjoyed carrying out simple optical experiments and conveyed his scientific curiosity and excitement to those nearby. For the first year at the Raman Research Institute there was no electricity, but that did not deter Raman from carrying out several beautiful optical experiments with sunlight, a few lenses and a pair of polaroids. He considered a beam of sunlight as the best source and in Bangalore there was no shortage of blue sky and bright Sun. A manually operated heliostat, kept-in order by voice communication produced astounding results. No wonder he discovered Raman efiect with equipment worth five hundred rupees !

Raman loved trees, flowers and among all, his rose garden. All the best roses that the Bangalore Nurseries could supply were brought and planted in his rose garden under his supervision, and he admired them like a child would admire a new toy. He knew the botanical names of every tree in the campus of the Raman Institute and had them planted carefully to maximize the effect of their floral display. Everyday, he would go round his garden twice, to enjoy, to relax and to think. Many a time he used to discuss physics with his research students, while taking a stroll in the Raman Institute grounds. Almost every evening, weather permitting, he would go to Cubban Park for a walk and on several occasions I have accompanied him. It was a delight to walk with him, for he kept constantly talking about Science, Nature and on topics that was uppermost in his mind. He had much confidence in me and would freely discuss plans for the Institute. When he went out of town he would entrust the affairs of the Institute to me. especially if Lady Raman went also with him.

Raman excelled in public speaking, and could give a lecture for instance on Egyptian History off his cuff. His scientific lectures were a treat and he was a superb entertainer. Once he told me that "the hallmark of a good speaker is that the audience must be under the delusion that they have understood everything." During the annual meeting of the Indian Academy of Sciences in Baroda in 1958, he interrupted the talk of a young high-energy physicist who was filling the blackboard with mathematical equations and said, "my dear fellow please try to explain what you have done, in a few sentences, if you cannot do this, it is not worth knowing," The Academy of Sciences annual sessions were jocularly known as Raman's circus, with Raman as the ringmaster. Raman articulated the proceedings and sat through every lecture' from high energy physics to biology, He would ask the most penetrating questions and make very entertaining comments. It is dangerous to give a talk before him that had no originality, for he called a spade a spade right in front of everyone.

Raman's lectures were painstakingly prepared and illustrated with colorful slides and diagrams. Often. I used to prepare these for him and he would like me to operate the projector. for he cannot stand an erring projectionist, Raman instantly appreciated a job well done and any good idea. I once photographed in color optical effects exhibited by several gem materials, and color photography in those days was still an art and not mechanized and automated as at present. Raman took the film with him to Bombay and had it processed, The color slides had turned out so good, he was tremendously happy, Instantly he sent an express telegram to me back in Bangalore conveying how pleased he was with the outcome. Not only he expressed openly his appreciation and admiration for good work but he also acknowledged in public. how so and so did a marvelous job, discovered something nice, and had a good idea.

He gave tremendous encouragement to his research students and discussed their scientific problems in detail. His students and collaborators had unlimited and unrestricted access to him and did not need an appointment to see him.

Maharajas, prime ministers, politicians, officials, students and laymen listened to Raman with wonder, and viewed his scientific experiments with awe and admiration. His vast collection of gems and minerals and Raman's inspiring tales enthralled them. Raman loved to show the panoramic views of Bangalore from the first-floor Portico and veranda of his Institute, which was spectacular, Since the Raman Institute was situated on a high elevation near the perimeter of Bangalore, a splendid view of the city and its environment unfolded on the southern side, while on the northern side it was the vast open space with Nandi hills adorning the horizon. Raman's descriptions varied, depending on his moods and to whom he was talking.

Among the famous scientists who visited him during the years 1950-1960, I remember vividly the visits of S. Chandrasekhar, J. D. Bernal, P. A. M. Dirac, Linus Pauling, Norbert Wiener, C. G. Darwin, P. M. S. Blackett, J. B. S. Haldane. George Gamow, H. J. Bhabha, C. F. Powell and others, Among leaders, politicians and other prominent citizens, whose visits I remember are Rajendra Prasad, Jawaharlal

Nehru, Indira Gandhi, Mirza Ismail, M. Visvesvaraiah, Sri Prakasa, Jayachamarajendra Wodeyar. former Maharaja of Mysore, and the former Maharaja of Travancore.

Raman Museum

Raman loved to collect gems, minerals, rock specimens and even shells. He also had a fascination for stuffed birds, beetles and butterflies, which displayed colors. The specimens were neatly arranged in glass shelves and were lighted appropriately for the best possible viewing. One little room had luminescent minerals and these came to life with brilliant colors when the UV light bulbs were turned on. This was one of the thrilling experiences for a visitor to the Raman Institute. When this section of the museum was put into operation Raman must have turned the UV lights on and off a hundred times. each time enjoying the sight like a child.

Quartz was Raman's most favorite mineral, not only for its scientific value but also for its aesthetic appeal. It can occur in varied forms and color; from clear absolutely colorless form symbolizing purity at the one end. to an opaque mineral constituent in igneous rocks at the other end. Raman had an exquisite collection of quartz crystals and quartz family minerals. single crystals, clusters and carved specimens filled the shelves. He was never tired of acquiring quartz crystals. although he would say he would not go in for anymore of quartz. There was a man from Coimbatore who used to work for the Telegraph Dept. He would bring quartz crystals. small and large to sell, and Raman's resolution would breakdown on the sight of the material. It ts interesting that he had two small quartz crystals with iridescent faces. the like of which I have not seen anywhere so far. His collection of amethyst was exquisite and Dr, Pancharatnam an illustrious pupil of Raman made good use of them in his researches. Raman himself wrote papers on the origin of color in amethyst. Raman conveyed this enthusiasm for crystals and minerals to all of us. In later days the inclination to collect became inherent in a few of us. Dr. Ramdas who is Professor of Physics at Purdue University and a pupil of

Raman has a beautiful collection of crystals. I built up a varied collection and enjoyed them before transmitting it on to my grandson.

Love of Diamond

Raman's love for diamond is well known. He had collected about 600 diamonds, of different kinds and origin. These were acquired from various sources, sometimes received as gifts and sometimes bought. He used them all in his studies, classified them according to their properties and boxed them beautifully. He had given special names to them and had a fund of stories about them. Raman was decorated with a diamond studded pendant with 63 diamonds in it by the Maharajah of Mysore. at the time he was honored with the title of Rajasabhabhushana. This beautiful piece of jewelry promptly entered into Scientific literature, for Raman studied the luminescence characteristics of the diamonds set in the pendant and drew several interesting conclusions about the nature and intensity of luminescence exhibited by diamonds, when excited by UV light. The diamond collection was kept under lock and key and were shown only to chosen visitors. A fortunate few saw the splendid luminescence of some of his brilliant florescencing diamonds, which was best seen with a beam of condensed and filtered sunlight in a darkened room; the filter was made of wood's glass which excluded the visible rays, admitting only the UV. Raman had christened a large tabular diamond as "my kohinoor" which exhibited a brilliant blue fluorescence when placed in the filtered and condensed beam of sunlight, almost lighting the room. Another gem-cut diamond named "green diamond" shone forth in dazzling green color when thus illuminated. As the diamonds came to life with their brilliant fluorescence, Raman's eye lighted up in step and his expression "Isn't it beautiful" was contagious. Anyone who saw this could never forget either the diamond or Raman's way of communicating an aesthetie experience.

Physics of Diamond :

Raman had a special interest in the physics of diamond and came back to it several times during his lifetime. First he was interested in understanding it's vibrational spectrum, which led him to formulate his theory of lattice dynamics. Then he proposed that there existed two forms of diamonds, which he based on certain characteristic properties diamonds showed. From a study of the diffraction of x-rays by diamond, Raman proposed a new kind of x-ray reflection which he chose to call "quantum x-ray reflections." He came back to the subject again and again and filled the Proceedings of the Indian Academy of Sciences with his memoirs.

According to Raman, carbon atoms, which have s-p bonding, form a crystalline solid in diamond with tetrahedral symmetry (Td). This form lacking in center of inversion is UV and IR absorbing. blue luminescent etc, etc. The other form of diamond had full octahedral symmetry (Oh) and was UV and IR transparent and usually nonluminescent. Raman tried to fit birefringence and luminescence patterns, x-ray to, pographs and other properties of diamond in terms of these two forms of diamonds. He proposed that the above properties owed their origin to the interpenetration of these two forms. Although these ideas appeared to be consistent, some crucial experiments about 1958 established, that the difference in the physical properties of diamond were correlated with the presence of nitrogen as a substitutional impurity in diamonds and had nothing to do with its fundamental character. Diamond crystallizes only in one form namely Oh symmetry, having the full symmetry of the Cubic system. Further, the non-Bragg x-ray reflections exhibited by certain diamonds, which Raman believed originated from the interaction of the lattice vibration with the Bragg planes, were precisely those with nitrogen impurities in which the nitrogen had formed platelets, giving rise to non-Bragg spots.

We spent much effort and time in trying to measure if there is any frequency shift of the x-radiation reflected by the assumed non-Bragg spots. For this purpose we constructed a double crystal x-ray spectrometer with two of the best diamond platelets from Raman's collection. Although the double crystal spectrometer functioned beautifully and had excellent resolution it was impossible to say definitely whether there was any measurable shift. The whole problem was that the exciting x-radiation was of such high energy compared to the vibrational quantum, the change in wavelength would be infinitesimal, but our calculations showed that with a double crystal arrangement it would be just detectable. Raman was convinced that there should be a shift but the experiment was indecisive. Raman had a long drawn out controversy on the subject of the so called "quantum reflections" with K. Lonsdale of the University of London and there were many roughly worded exchanges between the two in the literature.

Raman and Lattice-Dynamics

Raman was very much obsessed with his theory of lattice dynamics and severely criticized Max Born and Debye. Most physicists who visited Raman Research Institute got a lecture on the subject and Raman would anxiously wait for acceptance of his ideas. Hardly anyone agreed with him and physicists who did not want to hurt his feelings remained silent. When Dirac visited Raman Research Institute, Raman gave a one hour talk and waited for Dirac's approval. Dirac was mild mannered and did not want to make any direct comment for fear of hurting Raman apparently. Raman interpreted this as approval of his ideas and praised Dirac for agreeing with him. I am sure Dirac would have seen through the fallacies in the arguments but he did not have a chance to say anything further and there ended the matter. Raman was certainly under the delusion that he had the support of Dirac for his views.

While the entire community of solid state physicists believed in the validity of the Born-von Karman model of lattice dynamics, Raman was the only physicist who stood apart, believing his views were the correct ones, To take such a stand needs tremendous courage and conviction and Raman never lacked either of these. Scientific controversies per se are not bad at all. Often bold ideas and new concepts are not easily accepted. However this controversy sidetracked Raman from his real leanings, and proved counterproductive for him. It led to a tremendous frustration in him and he wasted a lot of time and energy in trying to convince others about the validity of his theories. The inelastic neutron work had unambiguously proved the correctness of the Born-von Karman model, but Raman would not accept these experimental confirmations, which is uncharacteristic of a superb experimentalist. Raman would have done more interesting things in optics, if he had not involved himself in this. He was an experimentalist par excellence and his intuitive ideas often jumped many steps ahead of theory. All these in no way diminish Raman's greatness and his place in the world of physics. I mention them, because they were part of his life and personality.

Last Days

Raman did not approve of scientists from India going abroad for training and research, and was very much upset when I left in 1960 to take up a post-doctoral position at the University of California. It was also a very difficult decision for me to leave him, but he was too angry and too upset to give me a leave of absence. It took many years for him to accept the fact that my decision helped me in my scientific growth. In Dec. 1968 I went to Ahmedabad for the Annual meeting of the Indian Academy of Sciences which was specially arranged to celebrate his 80th birthday and he was very happy to see me at the event. He was moved when I presented him with a gift of beautiful synthetic crystal collection which included a large number of synthetic diamond crystals. He seems to have remarked to someone later "Jayaraman knows how to touch my heart. Unfortunately I am not able to do him anything in return that is good enough to attract him back to the country." When I saw him in Ahmedabad in 1968 Dec. and later in Bangalore Jan. 1969, the age told upon him. Raman had a majestic bearing and moved around swiftly, but in 1969 he had grown feeble and became tired out easily.

In October 1970 when I arrived in Bangalore to spend a sabbatical year and to set up facilities for high pressure research in

India, my first duty was to pay my respects to my Guru. In the intervening period, between Jan 1959 and October 1970 Raman had suffered set backs in health and was not the old self. I saw him in his bungalow briefly and he came out of the bed to talk to me. That was unfortunately to be my last conversation with him. In a few days he went into the hospital after a heart attack and his condition appeared to improve, but within a few weeks he expired. Death is inevitable but you don't want it to come to someone who changed your life and made it worthwhile. I was in silent tears to see my revered Guru pass away but the only consolation was that I could be present to rest his soul in peace. I would have felt very bad had I missed paying my homage and last respects to him.

Epilogue

Raman made a discovery which will never be forgotten. With the advent of lasers, interest in Raman spectroscopy has grown by leaps and bounds. Raman scattering has become the most important tool in solid state physics. Today we not only call the inelastically scattered light from the vibrational modes as Raman Scattering but also light scattering processes which involve electronic and magnetic excitations. The usefulness of Raman effect in chemistry is too well-known. Even in biology the application of Raman spectroscopy is becoming indispensable. It has even found Industrial applications. Thus Raman's discovery has made a great imprint in science in a broad sense and makes India and Indian scientists feel proud of his achievements. Some of us who have known him intimately can never forget the greatness of the man and his life. It has been said of Raman that he was a "Rishi" in modern garb. He certainly had the concentration required of a "Rishi". Further he was a strict vegetarian and teetotaller. Above all he was totally dedicated to science and science was his first love. Raman's life should be a lesson and example to every aspiring student of science.

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PIONEER SCIENTISTS IN PRE—INDEPENDENCE INDIA

WILLIAM A. BLANPIED*

The conviction that scientific rationality can lead to intellectual liberation and thus convey benefits to a society that are at least as important as the material benefits derived from research has been central to Western thinking since the 17th century. That conviction is evident, for example, in the career of Benjamin Franklin, and is reflected in most of the official documents associated with the establishment of the American Republic. Studies by several scholars most notably Joseph Needham in his *Science and Civilization in China*—indicate that the development of science in other societies has also been deeply rooted in a cultural tradition of tolerance. If so, then it can be argued that neither modern science nor the conditions required to capture its tangible benefits can thrive in any society unless science can be harmonized with the cultural traditions of that society.

In this article I will consider the careers of six pioneers of physics in India.

Jagadish Chandra Bose, who died a decade before his country achieved independence.

Prafulla Chandra Ray, a chemist who was almost an exact contemporary of Bose.

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Chandrasekhara Venkata Raman, who was the first internationally recognized physicist to receive all his education in India.

Satyendranath Bose, known primarily for his contributions to Bose--Einstein quantum statistics.

Meghnad Saha, whose principal research contributions were made prior to independence.

Homi Jehangir Bhabha, whose publications in nuclear and cosmic-ray physics spanned the pre- and postindependence periods.

In their careers these six, like many other non-Western physicists, were in the vanguard in defending both the universality of science and its importance to their society. As Raman put it,[1]

> Unless the real importance of pure science and its fundamental influence in the advancement of all knowledge are realized and acted upon. India cannot make headway in any direction and attain her place among the nations of the world......There is only one solution for India's economic problems and that is science and more science and still more science.

Abdus Salam, who as director of the International Centre for Theoretical Physics at Trieste has devoted much of his inspired energy to improving conditions for research in less developed countries, has identified[2] "the supply of towering individuals, the tribal leaders around whom institutes are built," as "first and foremost among the factors that effect advanced scientific research in the developing countries."

In India; the conviction that a firm basic-research infrastructure is a necessary prerequisite to long-term technological progress dates back to the last century. Thus in 1901 Mahendralal Sircar, a farsighted Calcutta physician who had campaigned for 25 years to establish facilities for modern scientific research in India, maintained[3] that "educated patriotic gentlemen are wasting their energies in the vain endeavour to promote technical education without even thinking about the necessity of a preliminary scientific education."

The six "tribal leaders" whose careers I consider here not only did pioneering work in physics, but also helped establish the institutional and financial bases for doing fundamental research in physics in India.

Roots of science in India

One of the most enduring, if unintended, consequences of the long period of British rule in India may have been the idea that the cultures of Asia and Europe can be harmonized for their mutual enrichment. Although that idea was ridiculed by the British colonial government during much of the 19th and 20th centuries, it originated with an earlier group of British civil servants who in 1784 established in Calcutta the world's first society dedicated to scholarly studies of Asia, particularly India. Self-consciously modeled[4] on the Royal Society of London, the Asiatic Society of Bengal had as its objectives to explore "the History and Antiquities, the Natural Production, Arts, Sciences and Literature of Asia" and, even more grandly, to make inquiries into "Man and Nature, whatever is performed by the one, or produced by the other."

It is thus probably no accident that five of the six pioneers I consider here—Bhabha is the exception—all spent at least the formative years of their active scientific careers in Calcutta. As the administrative center of the Presidency of Bengal and later (1774-1921) the capital of all British India, Calcutta offered Indians the earliest, best and most sustained opportunities to be exposed to modern science and to reflect on its implications for their own society. Indeed, from 1915 until 1921, the activities of J. C. Bose. P. C. Ray. C. V. Raman. S.N. Bose and M. N. Saha, among others, made Calcutta for a few years one of the most intense sites of scientific activity outside of Europe.

The Asiatic Society provided the nucleus about which this scientific culture was able to grow. One of the first to argue that there was an intimate connection between modern science and genuine self-reliance was the 19th-century Bengali reformer Ram Mohun Roy a member of the society. While Roy, was devoted to his own country's traditions, he believed that their ossification was a principal cause of India's subservience to Britain. Motivated by his belief that the spirit of modern science had to be an integral part of the rejuvenation he sought, he raised, in 1816, a private subscription to establish the Calcutta Vidyalaya, the first school open to Indians to offer instruction in both European and Indian subjects in the English language. Seven years later, in a memorandum addressed to the Governor General, Lord Amherst, Roy asserted[5] that "as the improvement of the native population is the object of the Government, it [should] consequently promote a more liberal and enlightened system of instruction, embracing Mathematics, Natural Philosophy, Chemistry, Astronomy with other useful sciences."

The first-rate science education Roy asked for was not to be forthcoming for at least another half-century. For by the time he addressed his 1823 memorandum to Lord Amherst, such prominent English intellectuals–as–James Mill, Charles Trevelyan and Thomas Macaulay and their political allies in the Liberal Party were openly ridiculing the idea that Indian culture had anything of value to offer Europe—or, in the extreme view of Macaulay, anything of value at all. Within another ten years, the colonial government was basing its policy on the explicit presumption that European culture was so innately superior to any Eastern culture that Europe had a moral obligation to impose its institutions wherever it possessed the political power to do so.

Thus when the colonial government began to establish schools, colleges and universities in the mid 19th century, it did so with the objective of training Indians for subordinate civil-service positions rather than providing them with a broadly based liberal education. As a result, throughout the 19th century and well into the 20th century even the best science instruction available to Indians was far from the best that Europe had to offer. Still, there were by 1870 at least three institutions in Calcutta teaching the rudiments of modern science. Judging from the careers of J. C. Bose and P. C. Ray, they must have taught it well enough to encourage an occasional exceptional student to think seriously about a scientific career.

The first of these institutions was the Medical College of Bengal, established by the colonial government in 1835 to train Indians as medical technicians. The Medical College was the first and for many years the only institution in British India with facilities for any real laboratory science.

The second of these notable schools was Presidency College. It was a government-run institution and was affiliated with Calcutta University.

Finally, perhaps the best scientific instruction in Calcutta. and probably in India, was offered[5] at St, Xavier's, a private, Jesuit school. St. Xavier's owed its reputation for excellence in science teaching primarily to its rector, Father Eugene La Font, a Belgian physicist who spent more then 40 years teaching there and became renowned in Calcutta for his public lectures and demonstrations.

La Font was a close friend of Sircar, whose views on the importance of science to the modernization of India I have already cited. Soon after his graduation from the Medical College of Bengal, Sircar scandalized his British mentors and colleagues by openly asserting that European medieal theory and practice were not in any *a priori* sense superior to traditional Indian medicine. In an effort to establish Indian medicine on a more scientific basis, he founded, in 1868, the *Calcutta Journal of Medicine*. Three years later this advocate of traditional Indian medicine put forth[6] in that journal a scheme for an "Indian Association for the Cultivation of Science," where young Indians would have the facilities and opportunities to engage in scientific research on the same footing as their European counterparts. Because Sircar saw the association as a key to genuine independence, he insisted that it be established and supported entirely by the Indian community, with the British authorities giving little more than their acquiescence. He campaigned vigorously to raise funds for the association, saw it established in 1876 and fought to expand its scope throughout the remaining 27 years of his life.

Sircar's Indian Association for the Cultivation of Science was the first of two centers of modern science in Calcutta. The second was established through the vision and energy of his younger colleague Astoush Mookerjee, a gifted, published amateur mathematician, judge of the High Court at Calcutta, active member of the Asiatic Society of Bengal and, from 1912 on, vice-chancellor of the University of Calcutta. Mookerjee succeeded in raising sufficient funds, principally among his Bengali compatriots, to establish a college of science at the university. This institution was to be the first in India to offer postgraduate instruction in mathematics and science. The funds raised by Mookerjee were sufficient to endow the first professorial chairs reserved for qualified Indian scientists—among them the Palit Professorships of Physics and Chemistry, whose first two occupants were C.V. Raman and P.C. Ray.

'Tribal leaders'

Thanks to the vision and labor of Sircar, Mookerjee and their supporters, Roy's half-century-old dream that Indians would achieve distinction in world- class science on their own terms now began to be realized. Four of the six pioneers I consider here were among the first faculty of Mookerjee's University College of Science. The oldest of the six, however; was well advanced in his career before that college was established, the youngest was able to build on the others legacy elsewhere in India.

Jagadish Chandra Bose was the first Indian to establish an international scientific reputation.[7] He was born in 1858 in East Bengal –now Bangladesh–and in 1879 received his bachelor's degree from St. Xavier's College' where he was a protege of La Font. In 1880 Bose traveled to England with the intention of studying medicine. However, with the encouragement of Lord Rayleigh, he decided instead to enroll in Christ's College, Cambridge, to pursue pure science. He received a BA degree from Cambridge and a BS degree from London University in 1884. and was awarded the DSc degree from London in 1896.

Following his return to Calcutta in 1884, Bose became the first Indian professor of physics at Presidency College, where he remained until he retired from the government education service in 1915. Originally Bose's salary as a professor was only two-thirds of that of British professors with comparable duties; when he discovered this Bose refused to take any salary at all, yet continued to teach on the grounds that teaching was an honor. The government authorities yielded within a year to that particular example of what Gandhi later made famous as "active nonviolence." In 1917 he became director of the Bose Institute, a research institution in Calcutta modeled after the Royal Institution in London and endowed from the proceeds of Bose's investments, private benefactions and a public subscription. He retained, that position until his death in 1937. Bose was knighted in 1917 and elected to Fellowship in the Royal Society in 1920.

During the first phase of his research career, which extended until about 1902, Bose was concerned with the generation, reception and optical properties of electromagnetic radiation in the unexplored wavelength range from 5 mm to 1 cm. His first paper, on the polarization of electromagnetic waves by double refraction, was published in 1884 in the *Journal of the Asiatic Society of Bengal*. A refinement and extension of that research was communicated to the Royal Society by Lord Rayleigh a year later. For the next few years Bose carried out detailed investigations of the receiving properties of semiconducting materials and worked on photoconductivity.

In 1895 Bose gave a public lecture at Town Hall, Calcutta, in which he demonstrated for the first time wireless transmission of electromagnetic signals through solid walls; it quickly made him famous throughout Bengal. As a result of that growing fame, the government of Bengal sent him on a nine-month lecture tour of Europe, where in December 1896 he repeated his demonstrations of wireless transmission at the Royal Institution before an audience that included Lord Kelvin. That event anticipated by a year Guglielmo Marconi's more celebrated (and commercially exploited) wireless-transmission demonstrations in the same city.

In 1900 Bose became intrigued by the similarity in the absorptive responses of organic and inorganic matter to centimeter- wavelength radiation. During the next 30 years his research focused increasingly on comparative physiology, particularly plant physiology; he thus qualifies as one of the first biophysicists. For his explorations of the behavior of plants and of plant tissue, Bose devised a set of ingenious instruments to magnify and record extremely small movements in plants.

The colonial government in India recognized and sought to take advantage of Bose's international reputation by sending him abroad as a member of ten scientific delegations between 1896 and 1931. For his part, Bose was conscious of the example he was setting as a leader in the resurgence of Indian culture (and particularly Bengali culture) that Roy had advocated during the 1820s and 1830s.

One important aspect of Bose's cultural leadership was his 30-year friendship with the Nobel Prize-winning poet Rabindranath Tagore, as recorded by their extensive correspondence in Bengali. Bose was among the first to urge that Tagore's work be translated into English. Bose's influence on Tagore's thinking is evident in the textbook entitled *Our Universe*, which the poet wrote in Bengali in 1931 for use at his school at Shanti Nikaten. Remarkable both for its literary quality and for its grasp of the science of that era, this work ranks as a classic in the history of the popularization of science.

Bose himself was a talented poet and published several articles in Bengali literary journals. He also served for four years as president of the Bengali Literary Society.

Prafulla Chandra Ray who was born in East Bengal in 1861 was the second most senior of the Calcutta group.[8] After studying for two years at Metropolitan College, Calcutta, he received a scholarship to the University of Edinburgh, where he was awarded a BSc degree in 1885 and a DSc degree two years later for his research in inorganic chemistry. In 1889 Ray received a special appointment as lecturer at Presidency College, Calcutta, where J. C. Bose was already teaching, and soon became professor of chemistry. He remained there until 1916, when Mookerjee summoned him to the University College of Science. There he continued his research and teaching for another two decades, long after he became eligible to retire. He was knighted in 1919.

Ray was first encouraged to pursue research by Sir Andrew Pedlar, principal of Presidency College and a chemist, who is credited with having carried out, during the 1890s, the first significant investigations on the chemistry of cobra venom. With Pedlar's help. Ray raised funds to equip a reasonably good chemistry research laboratory at the college and began a search for some of the missing elements in the periodic table. While engaged in that search he managed to precipitate mercurous nitrite, a compound that had been regarded as unstable, in crystalline from. For several years thereafter, he and his students carried out a systematic exploration of the properties of mercury salts and range of nitrite compounds.

Like Bose, Ray lectured abroad on his researches, and his work received international recognition.

In addition to establishing a new school of chemical research, Ray was instrumental in laying the foundations for a chemical industry in Bengal. In 1901 he and a handful of former students started the Bengal Chemical and Pharmaceutical Works, Ltd, which by 1947 had grown into one of India's major chemical firms. He and his students also established the Bengal Pottery Works, the Calcutta Soap Works, the Bengal Enamel Works and the Bengal Canning and Condiment Works. Ray gave much of the money earned in these industrial ventures to workers, to students (as stipends and scholarships), to laboratories and to scientific organizations.

Like Bose, Ray actively promoted the ideals of traditional Indian culture, having abandoned Western dress and manners on his return to India in 1888. He too was a member of the Bengali Literary Society and also served as its president, for two years. His concern with the cultural roots of science is reflected by his scholarship in the history of science. The first volume of his *History of Hindu Chemistry* appeared in 1902 and the second in 1908. He was also an active supporter of the Indian independence movement, often urging greater participation on the part of his students.

Chandrasekhara Venkata Raman was born in 1888 in Tiruchirapalli, in what is now the state of Tamil Nadu.[9] He received his BA degree from the Hindu College of Vishakapatnam (where his father taught physics and mathematics) and his MA from Presidency College, Madras. Failing to find a position in which he could use his scientific talents, Raman joined the Indian Finance Department in 1907 and was assigned to a position in Calcutta, where (with brief interludes) he served for ten years. He discovered the Indian Association for the Cultivation of Science soon after his arrival in Calcutta, and began to conduct research there before and after his working hours at the finance department. By 1917, when Mookerjee appointed him to the Palit Professorship of Physics at the University College of Science, he had authored or coauthored 25 papers published in *Nature*. the *Philosophical Magazine* and the *Physical Review*. Raman became Honorary Secretary of the Indian Association for the Cultivation of Science in 1919 and converted the association into the principal research arm of the College of Science.

Initially Raman's research focused on vibrations and sound and on the theory of musical instruments, particularly the violin family and Indian drums. That research led to his election to Fellowship in the Royal Society in 1924. Beginning in the early 1920s his interests turned increasingly to physical optics, a field that was to absorb him throughout his life. His interest in optics appears to have derived in large measure from his fascination with the aesthetics of color. For example, during the course of a roundtrip voyage to England in 1921 he became intrigued by the color of the sea. He convinced himself that its blue color cannot be ascribed completely to Rayleigh scattering. Fascinated with the aesthetic problem, he conducted[10] a series of experiments immediately after returning to Calcutta that led to the first adequate explanation of the sea's color.

Raman's early research in physical optics was concerned with the scattering of light by gases and liquids. Later he turned his attention to the optical properties of crystals, and—after 1950—particularly the optical properties of gems and minerals. His early investigations of crystal optics also led him to explore new approaches to the dynamics of crystal lattices, explorations that he carried over into his studies of gems. During the last years of his life, he focused[11] much of his attention on the physiology of vision. Although his ideas about color perception are provocative, most of his research in this field has been dismissed by contemporary physiologists.

Raman's best-known research contributions were an outgrowth of his research on the Compton effect in 1927. Having derived a semiclassical explanation of Compton scattering that attributed the wavelength shift of x–rays to the dynamics of the scattering electrons in their planetary orbits, Raman supposed that there might be an analogous wavelength shift in the molecular scattering of visible light, arising from dynamic fluctuations in the structure of the scatterers. These considerations led him to discover what is now called Raman scattering. An ardent nationalist, Raman first announced his discovery at the March 1928 meeting of the South Indian Science Association in Bangalore. It earned him a knighthood in 1929 (which he later resigned because of his strong nationalistic sympathies) and the Nobel Prize in 1930.

In 1933 Raman left his professorship in Calcutta for the privately endowed Indian Institute of Science in Bangalore, in the present state of Karnataka, where he served as president until 1937 and as head of the physics department until 1948. During these years his research interests turned to the diffraction of light by ultrasonic and hypersonic waves, Brillouin scattering and the scattering of light by colloids. After retiring from the institute he became director of the newly established Raman Research Institute in Bangalore, and retained that position until his death in 1970.

Raman was instrumental in establishing, in 1934, the Indian Academy of Sciences, and served as editor of its proceedings until

1969. Like all the Calcutta pioneers, he was noted as a great teacher and considered it "the principal function of the older generation of scientific men......to discover talent and genius in the younger generation and to provide ample opportunities for its expression and expansion". Although he was convinced that science had to play a central role in the economic development of India, there, is little doubt that it was also his conviction that science had to be pursued because it is integral to culture. As he said[12] in 1951. "Science is the fusion of man's aesthetic and intellectual function devoted to the representation of nature. It is therefore the highest form of creative art,"

Satyendranath Bose was born in Calcutta in 1894; in 1909 he entered Presidency College, Calcutta, where his teachers included J. C. Bose and P. C. Ray.[13] He received his MSc degree in mixed mathematics in 1915, ranking first in his class, with his classmate M. N. Saha ranking second. In 1916 Mookerjee appointed him and Saha as lecturers at the University College of Science. Two of his first four published papers (which were on statistical mechanics) were coauthored with Saha, and he and Saha translated Einstein's papers on special and general relativity in 1919; that translation, published by Calcutta University Press, was one of the first complete anthologies of those papers in English.

Bose left Calcutta in 1921 to become reader in physics at the newly established University of Dacca, Three years later, in July 1924, he sent a short manuscript entitled "Planck's law and the light-quantum hypothesis" to Einstein for criticism. In it Bose developed a method for deriving the Planck blackbody-radiation law without any reference to classical electromagnetic assumptions, a problem that had defied European physicists for almost 20 years. Einstein personally translated the paper into German for publication in the *Zeitschrift fur Physik*, and in a later paper extended the ideas to particles with nonzero mass.

Einstein's endorsement of his work earned Bose a two-year paid leave from Dacca to study in France and Germany. During his year in France he conducted experimental studies on radioactivity under

Paul Langevin and became closely associated with Maurice and Louis de Broglie. In late 1925 he had a brief and (by his own account) cordial meeting in Berlin with Einstein, whose interests by then had turned away from the statistics of identical "bosons."

Although the two years Bose spent in Europe witnessed the most pivotal developments in 20th-century physics, they do not appear to have had any direct influence on his subsequent research. His 26 published papers include contributions to statistical mechanics, ionospheric electromagnetism, x-ray crystallography and thermoluminescence.

Bose returned from Europe in 1926 to become head of the physics department at Dacca. He stayed there until 1945. when he returned to Calcutta as Khaira Professor of Physics. He was elected to Fellowship in the Royal Society in 1958.

As a teacher, Bose strongly encouraged his students, and often subsumed his own research contributions into papers bearing only the students' names.

He was deeply attached to and knowledgeable about the history and culture of India, stating on one occasion that he revered Gautama Buddha above all other human beings. He was a staunch supporter of Tagore's Bengali cultural renaissance movement and, like Tagore, loved poetry, which he read and quoted in Bengali, Sanskrit, English and French. In 1948 he founded the Science Association of Bengal as a means for popularizing science in his native language.

Meghnad Saha, born in East Bengal in 1894, was the most politically active of the Calcutta pioneers.[14] As I have mentioned, he received his undergraduate training at Presidency College, Calcutta, where his classmates included, besides S. N. Bose, P. C. Mahalanobis. who became founder and moving spirit of the Indian Statistical Institute, Rajendra Prasad, later the first President of India; and Subash Chandra Bose, who became one of Jawaharlal Nehru's most serious rivals for leadership of the Indian National Congress. Saha was appointed lecturer at the University College of Science in 1916. His first publications, which qualified him for a DSc. from Calcutta in

1918, dealt with electromagnetic theory, radiation pressure and the theory of stellar spectra.

In 1919 Saha was awarded a fellowship that enabled him to spend two years in Europe; five months with Norman Lockyer and Alfred Fowler at the Royal College of Science in London. and the balance of the time with Hermann Nernst at the University of Berlin. He returned to Calcutta in 1921 as the first Khaira Professor of Physics, but relinquished that position in 1923 to become professor of physics at the University of Allahabad, in the city that was the home of the Nehru dynasty. During his 15 years at Allahabad, he devoted a great deal of attention to teaching and organizing research in statistical mechanics, atomic and molecular spectroscopy, high.temperature dissociation of molecules and the physics of the upper atmosphere. Saha returned once more to Calcutta in 1938 as Palit Professor of Physics; there his research interests centered on nuclear systematics, the propagation of electromagnetic waves in the ionosphere, and the solar corona. When he retired from the university in 1953, he was appointed as the first Director of Laboratories at the Indian Association for the Cultivation of Science, He was elected to Fellowship in the Royal Society in 1928,

Saha's most original and significant scientific contribution was his research on the theory of high-temperature ionization and its application to stellar atmospheres and spectral classification. He began this work in Calcutta in 1919 and developed and refined it during his two years in Europe and the first years after his return to India. It remains the basis of much work on stellar atmospheres.

Saha began to become seriously interested in the use of science for economic development and national planning in the early 1930s, recognizing that a prerequisite would have to be the establishment of a closely linked network of modern research facilities. By that time he was already engaged in making Allahabad one of the most active centers of research in physics in the country. He established, in 1948. the Institute of Nuclear Physics at Calcutta University (which was renamed the Saha Institute after his death), and he improved the research facilities at the Indian Association for the Cultivation of Science. He also attempted to link the scattered university research centers in India into a strong national scientific community, but largely failed in those efforts because of a chronic lack of funds, a paucity of well-trained scientists and the bureaucratic organization of the university system.

In 1935 Saha founded *Science and Culture*, a journal he was to use for the next 21 years as a means for airing his incisive views on such topics as national planning, public-sector industrialization, hydroelectric and nuclear power, and the modernizing role of science and technology—as well as on Indian art, archeology and science in the ancient and medieval periods. Beginning in 1938 he served as a member of the Planning Committee of the Indian National Congress, headed by Nehru, and from 1942 on he was a charter member of the Council for Scientific and Industrial Research. Saha was elected to the Lok Sabha (the lower house of Parliament) in 1951 as an independent, and frequently used that forum to criticize many of the government's policies for science, technology and development until his sudden death from a heart attack in 1956.

Saha had a serious amateur interest in Indian history and archeology, and published several scholarly papers in those fields. He was also an excellent teacher with the ability to provide his students with the breadth and confidence required to branch out in new directions. Many of his students and younger colleagues went on to play significant national and international scientific and science-policy roles in their own right.

Homi Jehangir Bhabha was born in 1909 in Bombay.[15] He was connected through the marriage of a maternal aunt to the Tata industrial family of Bombay and that association provided him with an understanding of business and industry. Likewise, his association with Cambridge University was to help give him access to Nehru, who was also a Cambridge alumnus. Both the Bhabha and Tata families were nationalists and received some of the most important of the independence-movement leaders, including Mahatma Gandhi, in their homes.

Bhabha enrolled in Gonville and Caius College, Cambridge, in 1927, where he expected to study mechanical engineering in preparation for an industrial career with the Tata enterprises. However, his obvious talent and preference for pure science led him to a BA degree in theoretical physics in 1930; Paul A.M. Dirac served as one of his tutors. He received his PhD in 1935 for research at the Cavendish Laboratory, Cambridge, on cosmic-ray-produced electron showers. Bhabha's research activities continued to revolve around the Cavendish until 1939. but he also traveled extensively on the continent, where he paid extended visits to Enrico Fermi's group in Rome, Wolfgang Pauli's group in Zurich and Niels Bohr's institute in Copenhagen.

Bhabha's most notable research contributions during his years in Europe included the first calculation (done with Werner Heitler in 1937) of the cross section for the production of electron--positron pairs by fast primary electrons, the first suggestion (1938) that the behavior of the observed "penetrating" particles in cosmic-ray showers could be attributed to "heavy electrons" (later identified as muons) and the first suggestion that the observed lifetime of muons should be governed by relativistic time dilation. Heitler was later to remark that the 20 scientific papers Bhabha published prior to 1939 were in themselves sufficient to have earned him a lasting reputation in theoretical physies. He was elected to Fellowship in the Royal Society in 1940.

Bhabha was vacationing in India at the outbreak of World War II in 1939. Unable to return to Cambridge, he accepted a readership in physics at the Indian Institute of Science in Bangalore and in 1942 was appointed professor of cosmic-ray physics.

The institute had been founded in 1909, largely through a donation by Sir Jamshediji Tata, a Bombay industrialist who, like several of his Calcutta contemporaries, believed that modern science held the key to India's selfreliance. In 1933, as I have mentioned, the institute lured C. V. Raman away from his Palit Professorship in Calcutta. With Raman's support and through his own Tata connections, Bhabha used his position in Bangalore to argue forcefully for development of a scientific and technological infrastructure for India.

In March 1944 he proposed to the Tata Trust the establishment of an institution that would be devoted to advanced research and teaching in mathematics and physics, particularly cosmic-ray and nuclear physics. He conceived of the institute as both a world-class center for basic research and an incubator for new types of industrial enterprises. The Tata Institute for Fundamental Research was founded at Bangalore in June 1945 with Bhabha as its first director, and set up temporary quarters in Bombay in December of that same year.

Bhabha was a strong advocate of a nuclear-power electrical system. When the Indian Atomic Energy Commission was established in 1948, Bhabha was made its chairman. The commission conducted most of its early research and development work at the Tata Institute. In 1954 the commission was reorganized as the Department of Atomic Energy, with Bhabha as its secretary; that same year Bhabha was appointed director of the Atomic Energy Research Center. construction of which was just getting under way at Trombay, a Bombay suburb.

Bhabha, a staunch advocate of international cooperation in science and technology, concluded agreements with the United Kingdom, Canada, France and the United States for assistance in developing the Indian atomic-energy program. He was the unanimous choice for the position of president of the First International Conference on Peaceful Uses of Atomic Energy, held in Geneva in 1955. He became a governor of the International Atomic Energy Agency at Vienna (established as one result of the Geneva conference) and a member of the Scientific Advisory Committee to its secretary-general. He died in January 1966 when an airplane carrying him to a meeting of that committee crashed on Mount Blanc.

Bhabha conducted research until he became Secretary of the Department of Atomic Energy, authoring or coauthoring more than

60 papers in cosmic-ray physics, nuclear physics and meson theory between 1933 and 1954. Although he engaged in formal teaching only during his years in Bangalore, his influence on his contemporaries and younger colleagues at the institutions he established was enormous and lasting. He also had considerable influence with Nehru, who came to rely heavily on his scientific advice.

Bhabha had a deep aesthetic attachment to both music and art. As a boy he had learned to appreciate Western classical music by listening to the extensive record collections of his grandfather and aunt, and he refined that appreciation and knowledge during his years in Europe. Upon his return to India he began to immerse himself in the study of Indian classical music, and later he became a patron of contemporary Indian art. He personally selected the permanent sites of the Tata Institute and of the Trombay Atomic Research Center, and worked closely with the architects in designing both complexes.

Physics and development

While it is hazardous to generalize from six cases, three conclusions suggest themselves.

Basic research conducted in less developed countries, under far from optimal conditions, can contribute significantly to international scientific progress.

Basic-research activity can also make substantial contributions to the less developed country itself.

The contributions to the country most frequently do not flow directly from the results of the research.

For example, the results of J. C. Bose's research on centimeter-wavelength radiation were certainly applicable to the radio communications industry. But neither Bose nor any other Indian scientist was involved significantly in the development of that industry, even though some of Bose's critical results probably anticipated Marconi's. Likewise, a 1930 prediction by Rutherford that Raman scattering would become a powerful analytical tool turned out to be correct, but India reaped no direct economic benefits from it.

Of course there is nothing particularly novel or unusual about the fact that Bose's and Raman's results were exploited elsewhere and after a considerable lapse of time. But it does suggest that the value of basic research to a less developed country—or to any country—cannot be assessed in terms of how well that country succeeds in capturing for commercial purposes the results of the basic research conducted within its borders. The ability of a less developed country to capture basic research results that originate elsewhere may be a far better measure of its scientific capabilities. And as Bhabha persuasively argued and later demonstrated, training in basic research can provide the breadth and flexibility required to recognize promising scientific leads, wherever they arise.

Of all the physicists I have discussed, perhaps the least influential was S. N. Bose. Despite Einstein's favorable impression of his early research, he made no obvious direct contributions to the development of India's science-and-technology infrastructure. possibly because he largely remained isolated in Dacca except for the two years he spent in Europe in the mid–1920s. In that respect his career bears at least some superficial similarities to the earlier career of Josiah Willard Gibbs, whose profound contributions to thermodynamics while he was a professor at Yale remained largely unrecognized in the United States during his own lifetime. Indeed the case of Bose (and that of Gibbs before him) provides a graphic illustration of the plight of the isolated scientist in a less developed country—a general point made repeatedly by Salam.

Physics and culture

The careers of all the scientists I have discussed demonstrate the aptness of Needham's metaphor likening science to a great river that has received contributions from the separate streams of many different cultural traditions. Modern science thus need not conflict with the cultures from which those other scientific contributions sprang, but rather should reinforce the liberating cultural traditions of any society. Perhaps the connection between what these six men saw as the value of basic research and the necessity of basing modern science in India on Indian cultural traditions is simply this; At its best basic research aims to satisfy human curiosity. But curiosity is among the most innate and universal of human characteristics, so its systematic and disciplined pursuit need not do violence to any culture. On the contrary, it should harmonize with the best of that culture.

If this proposition has any merit' then perhaps the encouragement of basic research in a less developed country is a necessary precondition for the establishment of a stable basis for a modern technology. Sircar emphasized[16] this point in one of his earliest appeals for support for the Indian Association for the Cultivation of Science.

We are so constituted that we must either go forward, or be driven backward; we cannot remain stationary. There is an immense difference between the civilized man and the man happening to live in civilized times. Such incidents of birth will never endow us with the privileges of the times in which we live, unless we render ourselves worthy of the same.

More than three centuries earlier, at the very birth of modern science in Europe, Francis Bacon concluded[17] the preface to his *Novum Organum* with a stern warning to those who aspired to pursue his vision of a new experimental philosophy:

> Lastly, I would address one general admonition to all; that they consider what are the true ends of knowledge, and that they seek it not either for pleasure of mind, or for contention, or for superiority to others, or for profit, or fame, or power, or any of these inferior things; but for the benefit and use of life; and that they perfect and govern it in charity.

Nehru, at one with the visionaries and pioneers who laid the foundations for modern science in India, believed that his country was particularly well equipped to heed Bacon's admonition to "perfect and govern (knowledge) in charity." In view of the vital importance that science has now assumed throughout the world, the ways in which India struggled and still struggles with the problem are worth pondering. But one may still ask, why pursue basic research in a less developed country ? J. C. Bose's friend Tagore gave[18] an answer:

> Whoever wishes,
> May he sit in meditation
> With eyes closed
> To verify if the universe be true or false
> I, in the meanwhile,
> Shall sit with insatiate eyes
> To see the universe
> While the light lasts.

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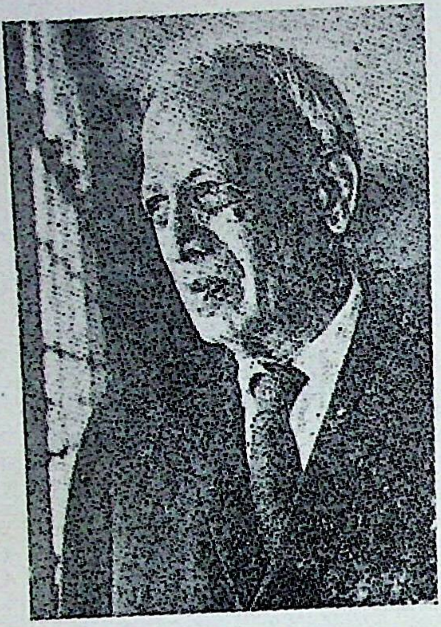

K. R. RAMANATHAN

Raman Professor, 1980

Ramanathan was born in Kalpathi Palghat, on 28 February, 1893. He had his early education at Palghat and Madras, where he obtained his Bachelor's and Master's degrees in Physics. He worked for seven years in the Department of Physics; Maharaja's College of Science. Trivandrum when he served also as Honorary Director of the Trivandrum Observatory.

He joined Professor Raman as a research student in 1921, and published ten papers on molecular scattering of light and X-ray diffraction in liquids, gases and mixtures, within one year and was awarded the D. Sc. degree of the University of Madras.

In 1922 he accepted a teaching appointment at Rangoon, but continued to work in Raman's laboratory, during vacations, on the molecular diffraction of light by water. Three years later he joined the India Meteorological Department as a Meteorologist. He retired from the Department in February 1948 as Deputy Director General and joined the Physical Research Laboratory, Ahmedabad as Professor of Atmospheric Physics and its first Director. He retired from the Directorship in 1966.

Ramanathan's research work in the India Meteorological Department covered a wide range of subjects, in each of which he has made basic contributions; solar and atmospheric radiation, the spectrum of the night sky, meteorological optics and acoustics, terrestrial magnetism, seismology, studies of the Indian monsoon and storms, depressions and cyclones in the Indian seas, and the general circulation of the atmosphere over India and its neighbourhood were all of equal interest to him but it is in the study of the thermal structure and movements of the upper air that his contributions are outstanding.

Ramanathan's research work at the Physical Research Laboratory was mainly concerned with studies of atmospheric ozone, night airglow, ionospheric and space physics, and solar and galactic influence on the ionosphere.

He was awarded the International Meteorological Organization prize in 1961, Padma Bhushan in 1965 and Padma Vibhushan in 1975.

PROF. SIR CHANDRASEKHARA VENKATA RAMAN*

K. R. RAMANATHAN
Physical Research Laboratory. Ahmedabad-9

CHANDRASEKHARA VENKATA RAMAN was born on 7 November 1888, at Tiruchirapalli, an important South Indian city on the banks of the river Kaveri. His father, Sree Chandrasekhar Iyer, was a teacher in a local High School. A few years after Raman's birth, Chandrasekhar Iyer accepted a post of Lecturer in Mathematics and Physics in the Hindu College at the sea-coast town of Visakhapatnam (Waltair). He was greatly interested in music and could play like a professional on many musical instruments. Raman's mother came from a family of Sanskrit scholars. Music, Light and Colour in Nature, rivers, seas. skies, mountains, forests and flowers had a fascination from his early childhood. Till the last day of his dedicated life, this wide-eyed gifted Child of Nature looked with penetrating eyes at different manifestations of Nature and laboured unceasingly to probe into their inner workings. His success in unravelling some of Nature's deeper secrets, and communicating some of his own enthusiasm for science to young people of all ages, both scholars and laymen, was outstandingly great.

At a lecture delivered at Bangalore on 16 March 1928,. Professor C. V. Raman announced the discovery made in the laboratories of the Indian Association for the Cultivation of Science, Calcutta, of the appearance of new radiations in the light scattered from several kinds of substances and briefly discussed the importance of the discovery. The announcement received immediate world wide attention. Intense work followed, and a few months later. in July 1928, Prof. Raman and Krishnan communicated a short paper of less than 12 pages to the *Proceedings of the Royal Society*, in which they summarised the knowledge gained in the first few months after the discovery. For the great significance of the results and beauty of presentation, the paper is a classic in scientific writing.

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*This article is adapted from an article written by the late Dr. K. R. Ramnathan in the Raman Memorial issue of Current Science in 1971.

The paper starts off in the following way; "In two preliminary papers, we have recorded the discovery that when monochromatic light is scattered by a transparent medium (be it gas, vapour, liquid, amorphous solid or crystal), the diffused radiation ceases to be monochromatic, and several new lines or sometimes bands (associated in many cases with a continuous spectrum) appeared in the spectrograms of the diffused radiation. Further, the radiations are, in general strongly polarised.

Our preliminary studies have proved conclusively that the effec. arises in the following way. The incident quantum of radiation is either scattered as a whole, in which case we have the classical scattering, or else is absorbed in part by the molecules of the medium, the remaining part appearing as a scattered quantum. The part absorbed shifts the molecules to a level of energy different from the initial state. Our experiments furnish definite proof of the possibility of such processes, and show that they may occur also in such complicated systems as the molecules of a vapour or a liquid or even a complete crystal."

In the course of the paper, the authors point out that the differences between the incident and scattered frequencies correspond to characteristic infra-red frequencies of the molecules and that several molecular frequencies, hitherto unknown, appear in these differences.

Three years later, in December 1930, when awarding the Hughes Medal of the Royal Society to Sir C. V. Raman, Lord Rutherford said as follows :

"Sir Venkata Raman is one of the leading authorities in Optics, in particular on the phenomenon of the scattering of light. In this connecstion, about three years ago, he discovered that the light's colour could be changed by scattering. This had been predicted sometime before, but inspite of search, the change had not been found. "The Raman Effect" must rank among the best three or four discoveries in Experimental Physics in the last decade. It has proved and will prove, an instrument of great power in the study of the theory of solids. In addition to important contributions in many fields of knowledge, he has developed an active school of research in Physical Science in the University of Calcutta."

In the same year (1930), the Nobel Prize for Physics was awarded to Sir C. V. Raman.

It is interesting to enquire how a fundamental discovery like this came to be made in India, and in 210, Bowbazar Street. The obvious answer is that Sir C.V. Raman was there in 210, Bowbazar Street, to make the discovery, and that he had been there for the previous twenty years building up step by step, with his students, the necessary background of knowledge and atmosphere. I give below a brief sketch of this constructive work.

C. V. Raman was an exceptionally gifted student. A very early paper of his in Optics on "Unsymmetrical Diffraction Bands Due to Rectangular Aperture" was written when he was about 18 years old a student in the Presidency College, Madras. Bright students there are every year, but students who produce firstrate research papers in their teens are rare. Three of Raman's research papers were published in 1906-07 in the *Philosophical Magazine* and *Nature*.

Soon after taking his M. A. degree in Physics with the highest honours, C. V. Raman joined the Government of India as an Officer of the Finance Department. Raman's interest in physics continued unabated, and wherever he was posted, whether in Calcutta, Rangoon or Nagpur, he continued to do research work and regularly contributed papers (mainly in acousties) to scientific journals. In Calcutta, he made a discovery. In 210, Bowbazar Street, a busy thoroughfare of Calcutta, there was an old institution called the Indian Association for the Cultivation of Science, with a laboratory and library established in 1874 by an enthusiast for science, Dr. Mahendralal Sircar. Except for occasional lectures, the Association had lain dormant for years. The institution had many spacious rooms with a good collection of old apparatus mainly of the demonstration variety. Raman requested the authorities to give him permission to work in the Institution. This was readily granted and Raman took up a house adjoining the Institution, had a door opened between his house and the Association so that he could reach the Laboratory informally for work at any time, by day or by night. A steady flow of brilliant scientifie papers, mainly on vibrations of strings and their maintenance and of musical instruments of the violin, veena and tabla families commenced. Raman also started giving evening lectures at the Association, expounding in his characteristically brilliant style with impressive demonstrations the results of his scientific investigations. All this naturally attracted the attention of Sir Ashutosh Mookerji who was then the Vice–Chancellor of the Calcutta University. When Sir Ashutosh was able to induce Sir Tarak Nath Palit to create Professorships in Physics and Chemistry in the Calcutta University, he immediately offered Prof. Raman the Chair of Physics. Professor Raman accepted the offer and, in 1917, when he was 29 years old, resigned his post in the Finance Department and became whole-time Professor of Physics.

The Association rapidly became an active centre of research. Several alumni of the Calcutta University, Dr. S. K. Banerji. Dr. B. Banerji, Dr. S. K. Mitra, Dr. P. N. Ghosh, Dr. N. M. Basu, Dr. B. B. Ray and others joined Professor Raman to work for their post-graduate degrees, also scholars from outside Calcutta like Mr. Chinmayanandan, Prof. Sethi, Dr. R. N. Ghosh and Dr. N. K. Sur. Optics and Acoustics were the main subjects of study. The Indian Association for the Cultivation of Science at 210, Bowbazar Street, and the University College of Science, 92 Upper Circular Road, became the main centres of scientifiic research in India. Problems on the interference and diffraction of light, and the scattering of light by large particles which are responsible for sunset colours, coronae and brocken-bows received special attention.

I went to Calcutta in December 1921 to work under Professor Raman and first met him in the rooms of the Indian Association for the Cultivation of Science. He had returned a few months previously from his first visit to Europe. His voyage across the wide seas had brought him face to face with a natural phenomenon of great grandeur and beauty, namely, the colour of the deep blue sea. During the voyage, he had studied various aspects of the light from the sea and sky with characteristic freshness of mind and came to the conclusion that the theories so far advanced to explain the deep blue colour of the sea were inadequate and that the primary origin of the blue colour of the sea was fundamentally the same as that of the blue of the sky, namely. the scattering of light by water molecules themselves modified by absorption in the red, and was not dependent on the presence of any suspended matter. After his return to India, he repeated and extended the experiments of Lord Rayleigh (the younger Rayleigh) on the scattering of light in dust-free liquids and sent a brilliant and comprehensive paper on the Molecular Scattering of light in water and the Colour of the Sea to the Royal Society. (*Proc. Roy. Soc. 1922.*) In this paper, he made use of the Einstein-Smoluchowski formula of scattering based on the thermodynamical fluctuations of density in fluids, to calculate the intensity and polarisation of the light scattered by sea–water. Mr. K. Seshagiri Rao, who was later an Examiner of Patents in Calcutta, was making quantitative measurements in the Laboratory to test with what accuracy the Einstein–Smoluchowski formula was obeyed in liquids under ordinary conditions.

There were other workers in the laboratory engaged on various problems in Optics or Acoustics. Prof. Laljee Sreevastava of Ajmer was working on the scattering of light by transparent crystals; ice and rock-crystal or quartz were the main crystals under study. Professor Raman had observed the blue colour of deep glaciers in the Alps. Professor Tamma of Meerut was working with crystals of sugarcandy and sulphur on the phenomenon of Internal Conical Refraction, Dr. Panchanan Das was working with paper and pencil on problems of vibrations of strings with frequent admiring recitals from Sommerfeld's 'Atombau' and Mr. V. Venkataramaiah of Vizianagram was setting up some glass apparatus or other for studying the properties of suspected H_3 (triatomic hydrogen). L. A. Ramdas and K. S. Krishnan were still students in the University College and Ramdas used to flit in and out of the laboratories of the Association, regaling his friends with music and jokes. Mr. Krishnan was an occasional visitor.

The next two years were years of intense activity in the development of the subject of classical molecular scattering by liquids and gases both in its experimental and theoretical aspects. The influence of the optical anisotropy of the molecules on scattering, scattering near the critical point in fluids and in mixtures of fluids, the problem of X-ray scattering in fluids, the systematic and methodical study of the scattering of light by different liquids, all these received attention and substantial progress was achieved.

One curious fact which appeared in my observations of scattered light from the deep blue water of the Bay of Bengal and from pure dust-free distilled water and also from pure methyl and ethyl alcohols was that when blue light was used to illuminate the medium, the scattered light had in addition a trace of light of longer wavelengths. This was at first attributed to "a feeble fluorescence". The same effect was found in many other liquids by Mr. K. S. Krishnan and Mr. S. Venkateswaran. Professor Raman did not feel satisfied with the explanation that the phenomenon was due to fluorescence and wondered whether this might not be akin to the Compton effect in X-ray scattering. When in 1927, Venkateswaran found that the colour of sunlight scattered by glycerine was a bright green instead of blue and that it was strongly polarised, Prof. Raman decided to probe in to the matter in greater detail with the assistance of Mr. K. S. Krishnan and Mr. Venkateswaran. Intensive work using monochromatic incident light eventually led to the discovery of the great effect, the story of which has been told by Prof. Raman himself at the meeting of the South Indian Science Association at Bangalore on 16 March 1928, and in greater detail in the Royal Society paper by Prof. Raman and Mr. K. S. Krishnan ("The Production of New Radiation by Light Scattering : Part I" *Proc. Roy Soci,*, A: 122, 23–35, 1929) and in Professor Raman's Nobel Lecture in 1930.

A related field in which. Professor Raman and Mr. K.S. Krishnan carried out a large amount of experimental and theoretical work between 1924 aud 1927 was electric and magnetic double refraction in gases, liquids and crystals aud their relation to the optical anisotropy of the molecules.

About a year after the discovery of the Raman Effect, Krishnan accepted the post of Reader in Physics in the Dacca Uuiversity and together with his students, carried out his well-known pioneer studies on magnetocrystallic action. The subject of Crystal Physics was later developed in great detail by Bhagavantam and his group at Waltair, and Prof. Raman himself and Dr. R. S, Krishnan and their students at Bangalore. All these had their seeds in the work done in Professor Raman's Laboratories in Calcutta in the twenties.

The atmosphere in the Association when. I worked there was one of great informality and extreme cordiality. All the workers lived either in the corner rooms of ihe Association or in rooms very near the Association; work went on from early morning till sunset with short intervals snatched for food and other personal requirements. The Assistant Secretary. Mr. Ashutosh Dey or Ashu Babu as he was affectionately called, with his loud voice and hearty laughter was always available to make all arrangements required for work and was the presiding deity to arrange all the smaller but none-the-less essential requirements for work–just as Professor Raman was the Central Sun round which the whole Institution revolved and from which each part derived its energy.

It still gives me a thrill of pride to think that I was privileged to work in those premises in those days and take a small share in the vital activities of the Association during the period 1921-24. After

I went to Rangoon as a Lecturer in the University in late 1922, I continued to be a periodic visitor to 210, Bowbazar' during summer vacations each year till I joined the India Meteorological Department in 1925. Later, Mr. K. S. Krishnan and Mr. Bhagavantam joined the Laboratory as full-time workers. Mr. S. Venkateswaran, who had a job in the Alipore Test House was a whole-time morning and evening worker.

In this context, I wish to quote a statement made by Prof. Raman in the broadcast talk on "the Scientific Outlook".

"The principal requisite for success in scientific research is not the maturity of knowledge associated with age and experience but the freshness of outlook which is the natural attribute of youth.

The principal function of the older generation of scientific men is to discover talent and genius in the younger generation and to provide ample opportunities for its free expression and expansion.'

In 1933, Prof. Raman left Calcutta for Bangalore on appointment as Director and Professor of Physics in the Indian Institute of Science. In 1934, he founded the Indian Academy of Sciences and became its President. *The Proceedings of the Academy* (Sections A and B) have since been published regularly every month without a single break. At the Indian Institute of Science, Prof. Raman and his students made extensive studies on Raman and infrared spectroscopy, X–ray spectroscopy, Brillouin scattering, ultrasonics, colloid optics, various aspects of crystal physics, etc,

In 1935, the Government of Mysore gifted to Professor Raman, as president of the Indian Academy of Sciences, 11 acres of land for constructing laboratories, libraries and other facilities for scientific work. A few years before his retirement from the Institute in 1948, Prof. Raman had arranged to build a new Research Institute, which now goes by the name of Raman Research Institute. After 1948, Prof, Raman continued to work in this Institute on the physical properties of crystals in relation to their structure, colours of minerals, iridescent shells, flowers, etc. Problems of floral colours and the Physiology of Vision interested him in the last few years of his life. Raman was very happy when, in 1964, the laser was applied to Raman Spectroscopy aud the Raman Effect began to be used to solve more difficult problems of molecular structure, and unstable particles in chemical reactions.

In September 1970, Professor Raman organized a whole week's meeting of the Indian Academy of Sciences at Bangalore. Young scientists were invited to present reviews of progress in different subjects–Nuclear Science, Radio Astronomy, Meteorology, Seismology, Crystallography, Genetics, Agricultural Science and Neuro-physiology. In spite of failing health, Raman attended all the meetings and, as usual, took an enlivening part in all of them.

Prof. Raman had a breakdown early in November and he passed away peacefully on the morning of 21 November 1970. His life companion, Lady Lokasundari Raman, and his Astrophysicist son, Radhakrishnan, were with him in his last days. His bodily remains were cremated on the grounds of the Institute.

Professor Raman's scientific achievements and infectious enthusiasm for science attracted motivated young men from all parts of the country. He trained them in scientific research and instilled self-confidence in them. When they went out into the world, they could grow on their own and create schools of research in Universities or, entering scientific services of Government, invigorate and improve them by research and development. Raman himself remained till the last days of his long and dedicated life, the wide-eyed Child of Nature, inquisitive about all aspects and phenomena of Nature and their inner workings, Again, quoting from one of Raman's broadcast talks: "Intellectual beauty is indeed the highest kind of beauty. Science is the fusion of man's aesthetic and intellectual functions devoted to the representation of Nature. It is therefore the highest from of creative art."

May the example and memory of Professor Raman's life and work, his courage, his faith in young men and women, and his ceaseless quest for Truth be an inspiration to the young people of our country.

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PROFESSOR RAMAN, "THE SCIENTIST-SAVANT" I ADMIRED*

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Who can write a near complete appreciation of our most colourful and dynamic personality of the community of scientists of modern India ? Who, indeed, could dare attempt to fathom the intellectual brilliance of a unique personality India lost on that fateful day, November 21, 1970 ? To many, he was just Sir C. V. Raman, a venerable figure full of honours and the tallest among Indian scientists of this century, but to some of us who were admitted into his 'inner court' he was THE PROFESSOR which conveyed everything that the title signified. Whether we belong to diverse discipline of biology, physics, mathematics or the earth sciences, he was our guiding star and we looked upon him not only as a Nobel Laureate in Physics but also as a sole representative of a fast dwindling group of scientists who could be called Naturalist Philosophers. For, who could have the courage to enter into fields like the Physiology of Vision or Floral Pigments (he coined a word 'Florachrome') or the colour of the sky or the oceans and make significant contributions ?

Ever since he built his own Institute, Professor Raman's wide interests in science became more apparent than ever. His collections of natural objects ranged from colourful minerals to diamonds, rubies and sapphires; every type of musical instrument from the mridangam to the violin; from birds, beetles and butterflies to the finest collection of roses, bougainvilleas and jacarandas; stately trees from the common eucalyptus to the rare mahogany—indeed, he was literally surrounded by a fantastic array of biological materials. I can never forget the way he laid two similarly dressed ores of copper and gold in the palms of the late Prime Minister Pandit Jawaharlal Nehru when he visited his Institute and switched on the ultra-violet light and asked the Prime Minister as to which was copper and which gold. The brighter piece under the ultra-violet light was promptly named gold by the Prime Minister and Professor Raman in his inimitable way burst out : "Mister Prime Minister, all that glitters is not gold."

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*This is an article written by Professor Sadasivan for the Raman Memorial Issue of Current Science (1971).

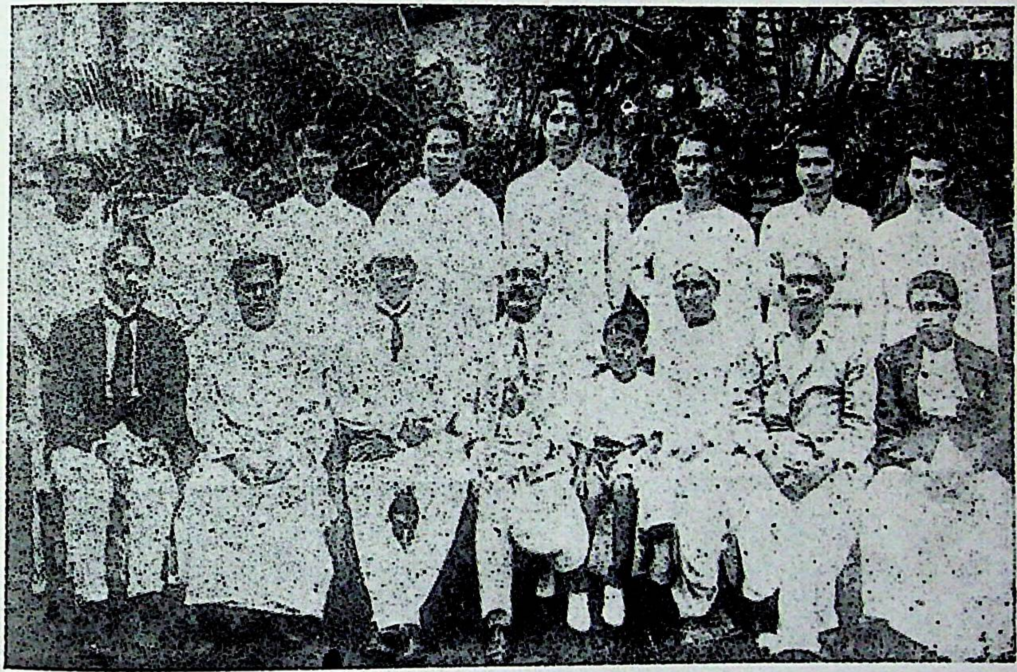
Professor Raman had some very definite views on fundamental research as Society's soundest investment for the future. He, nevertheless, conceded that while technological innovations had their own marketplace importance, the future of science unquestionably demanded a high place for fundamental research and the scientific community would have to understand the rationale of it all and make science play a positive role in our society than ever before. While he did not deprecate the interdisciplinary approach in many new fields of specialization, Professor Raman made no apologies about the awkwardness of groups of investigators sniffing around another's field of research for which they did not have the necessary training or competence.

In recent years, the Professor was much concerned with the rather poor quality of a good proportion of scientific papers that were submitted to Indian journals for publication. Despite this, he would promptly intercept any discussion at meetings on the need for tightening our systems of refereeing and declare : "Each man stands or falls by his own scientific writing." There can be little doubt that men of science in India owe a deep debt of gratitude to Professor Raman for his farsight in establishing the *Proceedings of the Indian Academy of Sciences* and the *Current Science* which have given generations of young men an excellent medium for projecting their scientific data. These organizations by themselves could make exacting demands on a scientist's time, but Professor Raman viewed it differently as his life's mission and a gift to the nation. Indeed, no sacrifice in the cause of science was too much for him; he gave his all to science.

Intensely national, on many occasions in recent years, Professor Raman had said in no unmistakable terms of his abiding and abundant faith in the young scientists of this country and this made him feel not so desperate as others when they took a dim view of the depletion of bright young scientific personnel through the much-publicized "brain drain". On the occasion of opening of a laboratory, Professor Raman, asked in a cryptic way : "Where are the brains to put into this magnificent building; remember, Radium was discovered in a tin-shed !" The proper attitude to science and scientific research was to him more important than major achievements which is given to the lot of very few men of science even in the most advanced countries.

I would like to end with a personal note. Looking back on my long association with this great savant, I can understand the big void the passing away of Professor Raman has created in Indian Science. He was one of those rare courageous men who would call a spade a spade. He would suffer no fools. I am reminded of a memorable occasion when many spoke at a special function got up to honour Professor Raman on his 80th birthday at one of the Annual Sessions of the Academy at Ahmedabad. When the last speaker had finished, Professor Raman appreciated the many warm sentiments expressed but pointed out, with a twinkle in his eyes, to the singular absence of any reference to one quality he proudly cherished : "I wish someone had said that I had the heart of a lion !" In fact, what I admired In him most was his simplicity and high thinking, indomitable in defeat and insatiable in victory.

We shall miss him at the Annual Sessions of the Indian Academy of Sciences and his brilliant Presidential Addresses and scintillating after-dinner speeches we shall miss himat the council Meetings of the Academy held in his Institute under charming wooded surroundings, we shall miss him when we are in need of encouraging advice and wise counsel and we shall miss - him most when a bold and authoritative voice would be needed to silence dilettantish attempts at introducing new science policies in our country in future. ●



Prof. Raman with Prof. A. Sommerfeld when the latter visited the Science Association (as the IACS was usually known at the time) at 619 Burobazar street.

PROFESSOR RAMAN'S GIFT TO OUR NATION*

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In recent years, increased emphasis has been laid on the need for changing the writing of history. It should not be simply a record of kings' reigns and wars and revolutions but should deal with more subtle and important factors that affect society and culture. In the evolution of the new complexion, historians of the right type should rise and be able to cope with the newer and ever-increasing demand on their ability and capacity to deal with factors that build up the mind and spirit of a nation. In this respect, Prof. Raman's life and work should be considered to be of great value for the progress of modern India.

The progress of a developing nation is some what akin to a man running uphill. This effort requires strength and experience. For the nation these are provided by institutions and traditions. The former represent the long shadows of great personalities who built them and the latter the disembodied spirit left behind by great workers and leaders and animating the nation. These two should be cherished as cumulative treasures by any nation that has success as its goal. In the area of science, Prof. Raman has left us both and they have to be preserved and cherished. It is significant that he valued science as his religion and this attitude of his may be understood and appreciated in the following two main aspects : (1) In the modern age of science, the welfare of a nation depends ever so much on the development of science, that its elevation to the level of religion with all its important implications becomes essential. (2) In a country like ours, religion has all along provided the basic inspiration for all worthwhile progress, revolution and renaissance and if science should make a marked impact, it should derive its strength from religion and should be associated with it in every way.

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*This article by late Professor Seshadri was first printed in the Raman Memorial Issue of the Current Science (1971).

Well-developed institutions act as eternal springs of ideas and inspirations. Scientists are familiar with the Cavendish Laboratory in Cambridge, the Kaiser Wilhelm Institutes in Germany and the famous Institutes of the Academy of Sciences in U.S.S.R. These Institutions do not age: on the other hand, they grow bigger and stronger with the passage of time. Neglect is a serious disease for them and will spell the nation's loss and diminution of strength just as in the case of a hall with damaged pillars. This neglect has been the cause of the backwardness of many nations. One of the characteristics that has been noted in backward communities is the repetitive process of unfruitfulness: doing, undoing and redoing. They lack the vision and the strength for maintaining and growing steadily to achieve progress. Prof. Raman has left us the Indian Academy of Sciences, Raman Institute and the journals associated with them, including *Current Science*, which he founded and conducted with energy and devotion all through his life. It becomes the nation's responsibility that they should be cherished and allowed to function with increasing efficiency. In the long but chequered history of most civilized nations, forts, palaces and similar military and political institutions were frequently destroyed by hostile forces and newer ones built. But continuity has been possible in the case of religious institutions. In spite of fanatical attack by certain religious groups, these institutions have continually functioned because of the protection given by the people. To some extent, some scientific institutions have also received this protection. Since science is an increasing force in modern times and has to advance progressively and rapidly, scientific institutions should naturally receive the devoted care of a nation, The success of most advanced countries lies in their efficiency in this direction. It should be remembered that scientific discoveries like the Raman Effect are the results of supreme mental and intellectual effort and dedication and should be valued for their cultural impact besides appreciation for rhe advance of science and arts.

Prof. Raman entered science like a fish jumping into water and was happy to do so; but this happened at a time when science was not attractive and was not prosperous. By dint of concentration, persistence and devotion to science, he was able to create an atmosphere and tradition which has a permanent value. These are intangible effects which are difficult to understand and follow up, but they have to be retained and cherished. We should pray that his example and his spirit will stay and grow and our scientists will be adequate in their strength to imbibe and cultivate the Raman spirit. He worked with extraordinary intensity and concentration of mind on any subject that he chose and produced great effect on his contemporaries. As an example. I remember one of his last lectures on diamond when he expounded the idea of intensive search for diamonds in the Andhra State which stirred many to action. In the more tangible way he has left a tradition of study in a particular area of science. He and his students by continual effort have created an excellent tradition for the study of optics and spectroscopy. There is considerable degree of expertise in our country in this field. This should be cherished and allowed to increase in rapid measure. If it could be ensured, it will not only serve as a monument of Prof. Raman but will also be a service to the nation and to the cause of science.

PROFESSOR RAMAN—THE ARTIST-SCIENTIST*

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and
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Early Interest in Music

If one were to summarise Professor Raman's life as a scholar, one would say that he was a scientist to the core. Science was the only thing that mattered to him and the pursuit of scientific enquiry was the one dominating impulse that led him through all his life. Even in science, Raman had always been fascinated by the beautiful part of it; beauty not only in the theory, but also in the objects and phenomena which he studied during his researches. It is not surprising that the earliest studies taken up by Raman were in the field of musical acoustics. Starting from the monumental work of Helmholtz, he devoted his time to the study of musical instruments, the quality of the musical tone and the theory of production of the musical tone by these instruments. His classical work on the theory of bowed strings is well known, and it is not at all surprising that the editors of the *Handbuch der Physik* chose Raman to write the article for them on "Musical Instruments and Their Tone" (1927).

Molecular Scattering of Light

The study of acoustics is intimately connected with the study of vibrations and waves, and it is not surprising that Raman's interests passed from his early love for acoustics on to a life-long devotion to optics, the other great domain of classical wave mechanics. In fact, if one may talk of a unifying trend in the scientific work of Raman, it may be said to reside in the study of wave phenomena. His very first paper, which he published as a young student when he was a teen-ager, studying in the bachelor's degree class of his college, was devoted to the diffraction of light. In fact, diffraction is nothing but the result of the interaction of optical waves with material media and this one aspect has dominated Raman's researches right from 1914 to the very end of his life. When he was called to take up the chair of Physics in Calcutta, he devoted his time immediately to the study of the diffraction of light by the molecules in a continuous medium, and came out with his first monograph on the "Molecular Diffraction of Light" in 1922. It was this interest in the interaction between light and matter that led him to study this subject in intimate detail during the decade of the 1920's, and which culminated in the celebrated discovery of the scattering (or diffraction) of light with change of frequency, which is known as the Raman Effect, in 1928.

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*Professor Ramachandran wrote this article originally for the Current Science Raman Memorial Issue (1971).

Photon-Phonon Interactions

The fact that the diffraction of light by a continuous medium is associated with the existence in it of acoustical waves, traversing the medium in all possible directions, was also enunciated during the 1920's, and this phenomenon is known after the name of Leon Brillouin, the well-known French scientist. Raman was fascinated by this type of interaction between one wave and another and sought to establish the possibility of there being a change in frequency of the light wave as a result of its interaction with the thermal sound wave in the medium. During the 1930's, a number of papers appeared from the Raman School in Bangalore in which this change in frequency was demonstrated by interferometric methods.

At about the same time, Raman realised that the same theory which explains the scattering of light as the interaction between light waves and thermal sound waves, in which the sound waves are incoherent and are going in all directions, could also be developed to take care of the coherent diffraction of light waves by sound waves. This phenomenon was observed in Germany in the early 1930's with ultrasonics, and the mathematical and physical theory of it was published by Raman and Nath in a series of papers which covered the ground almost exhaustively. Raman and Nath were able to show not only the conditions for the maxima in the diffraction of light to occur (which were analogous to the familiar formulae in optics dealing with the diffraction by a series of slits or a grating, and the wellknown phenomenon of the diffraction of X-rays by a crystal lattice), but also the distribution in intensity among the orders in the diffraction spectrum. The grating in this case is provided by the density stratifications induced by the sound waves, which produce a corrugated emergent wavefront.

Coherent Thermal Scattering of X-Rays

Both the Raman-Nath theory of ultrasonic diffraction of light and the observations on the hypersonic (Brillouin) scattering with change in frequency were made during 1934-37 and it is not surprising that Raman should have looked for an analogous phenomenon to occur in the diffraction of X-rays by crystals. As is well known, the usual diffraction of X-rays takes place from the periodic repetition of the molecular structure in the crystal in the form of a three-dimensional grating. Ideally, this leads to sharp "reflections" along specific directions given by the well-known Laue-Bragg conditions. However, if one considers that the static periodicity of the crystal is modified by a dynamic periodicity produced by the sound waves of thermal origin propagating through the medium (a phenomenon analogous to the Brillouin theory of scattering of light by media and the ultrasonic diffraction of light), then it is obvious that there should be intensity of X-rays diffracted in directions other than the Bragg maxima. Raman realised this and gave the correct description and formula for the direction of the nonlattice reflection of X-rays. He called it naturally the "dynamic reflection of X-rays" as this obviously arises from the existence of a dynamic periodicity induced by the thermal waves in addition to the static periodicity in the crystal structure. Raman and Nilakantan looked for the existence of such dynamic reflections and observed them in diamond and various other crystals. This discovery of the non-Bragg reflections in X-rays, made for the first time in Raman's laboratory in 1938-39, was confirmed by the work of several laboratories in other parts of the world almost simultaneously.

Analogy of The Raman Effect in Thermal Scattering of X-rays

In his proposal of the theory of the dynamic reflection of X-rays, Raman emphasized the occurrence of a change in frequency of the X-rays in its interaction with the thermal waves. Raman, in fact, called it a "quantum" reflection, and the title of the first paper by Raman and Nilakantan on this subject is entitled "Reflection of X-rays with Change of Frequency" and has a section entitled "Analogy with the Compton Effect". Although the change in frequency is negligible and has not been experimentally demonstrated even now, the importance of the change in frequency along with the change in direction of the reflected wave cannot be overemphasized. In fact, it is the combination of both these types of measurements that has made the diffraction of thermal neutrons by acoustic thermal waves (a phenomenon closely analogous to the diffraction of X-rays by thermal waves, both X-rays and neutrons in these examples being about the same in wavelength) of such great practical interest. Although, at the time of Raman's discovery of the thermal diffraction of X-rays, the diffraction of neutrons had not been demonstrated, he was probably the one worker of that period who emphasized the change in frequency, which later has found such tremendous application in neutron diffraction for the understanding of the frequency spectrum of crystals.

Raman's associates extended the study of the thermal scattering of light to crystals during the 1940's and early 50's, and both the change in frequency and state of polarization of the scattered light were recorded directly on a Littrow spectrograph and compared with theory. In fact, they were even used to measure the elastic constants of cubic crystals like diamond at such high frequencies.

Optics, The Beautiful

What has been stated above deals essentially with aspects of the fundamental physics of Raman's interests in the field of diffraction.

and its various manifestation. Simultaneously with all these studies, Raman had also been interested in the artistic aspects of diffraction and the beauties of Nature which are associated with diffraction effects, Starting from the classical work of Rayleigh on the scattering of light by the atmosphere and the explanation of the blue colour of the sky, Raman showed that the deep blue of the ocean is not a simple reflection of the, blue of the sky, but that it arose essentially from the molecular diffraction of the sunlight by the water molecules in the ocean. Meteorological optics had always fascinated Raman and he made several investigations on the colours of halos and coronae and other such optical phenomena in the atmosphere. He showed that the colours of iridescent shells, of the plumage of certain birds and of the wings of butterflies are to a large extent due, not so much to intrinsic pigments, but rather to the phenomenon of diffraction. In fact, Raman's laboratory contains perhaps one of the best personal collections in the world of examples of such beautiful colour effects exhibited by natural objects of varied origin. This interest in colour, arising from interference, diffraction, or from other causes, has always fascinated Raman and one could never talk to him for a few minutes without his growing eloquent about the artistry of such phenomena, and his taking one to his museum and illustrating his talk by practical examples from his collection. It is not surprising, therefore, that, during the last years of his life, he devoted all his attention to the understanding of colour vision and spent a considerable amount of his time on the origin of colours of flowers

The Bubbling Scientist

I cannot but take this occasion to mention the fact that I owe all my early initiation into the mysteries of diffraction theory and Fourier transforms to Professor Raman. The very first problem which he gave me when I joined him as a student was on the interference effects produced by stratified layers, which led to a novel derivation of the classical Darwin formula in the dynamical theory of X-ray reflection by a perfect crystal using a formulation for a finite number of stratifications proposed by Rayleigh before 1900. This was followed by a series of studies on the diffraction by spherical particles and particles of other shapes. In all these studies, Raman impressed on me the need to analyse any disturbance produced by the obstacle into their periodic Fourier wave components, which made a profound impression on me regarding the importance of the Fourier transform approach to the explanation of any phenomenon involving the interaction of waves with matter. In fact, in a series of lectures which Raman gave in Baroda on optics, during the time when I was a student of his, he systematically developed the use of such a plane-wave analysis for obtaining a simple picture of the optical phenomena occurring in various systems. Unfortunately, Raman could not complete the editing of the manuscript of the book based on his lectures during his lifetime, although they were delivered as early as the 1940's. In fact, he could never sit down to write anything systematically, because he was always bubbling with ideas, and was finding it necessary to make newer and newer studies in his research programme. In fact, if there is a message in Raman's life to our young scientists in India, it is that one should never give up thinking of new approaches in one's research. If I may put it humorously, it is better to have a wrong theory rather than to have no theory at all. If one ever met Raman and started talking science with him, one could not spend more than a few minutes before he came out with his pet theory of the moment—it might be on earthquakes, or cyclones, or the absorption spectra of anthocyanins. It is a pity that the enormous drive and energy that he had, combined with unbounded enthusiasm for the pursuit of pure knowledge, must have remained completely unutilised by the country for a number of years in his later life, for reasons which we need not enter here. But, if the younger generation would emulate the spirit of Raman and would follow in his footsteps in dedicating themselves to the service of Indian Science, it would be the best tribute that we can pay to the life and work of this great savant.

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PROFESSOR SIR C.V. RAMAN AS I KNEW HIM*

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The scientific genius of Professor Sir C. V. Raman began to blossom at the age of 16 or 17 while he was still a student at the Presidency College, Madras, and his passion for science continued unabated till the time of his passing away at the age of 82. For over six decades, he dominated Indian Science and inspired generations of scientists who loved, admired and revered him. He won the highest honours, laurels, distinctions and awards, both national and international, for his researches and discoveries. His life is truly a saga of science. With his versatility and penetrating intellect, he combined child–like simplicity and deep humanity which endeared him to all those who came in contact with him. It is difficult to write about him and the many facets of his personality without getting the feeling that one has not adequately expressed what one wishes to convey.

In 1933–five years after the discovery of the Raman Effect and three years after he was awarded the Nobel Prize—Prof. Raman moved from Calcutta to join the Indian Institute of Science at Bangalore. In the newly–created Department of Physics at the Institute he pursued his scientific activities for a period of 15 years. I was one among the first batch of 8 or 10 students, fresh from the university, who joined to work under him in August 1933 and I was associated with him for the next four years. Anyone who wished to work under Professor as a regular student had to undergo a searching oral examination in which the candidate's knowledge of fundamentals and capacity for original thinking would be severely tested. Although Professor attached importance to academic records, he always made his own assessment of a student.

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*This article was originally written for the Raman Memorial Issue of Current Science (1971).

Once having been selected, the students felt at ease with Professor. He was kind, generous and large-hearted. He had his own way of developing self-confidence and selfreliance in his students. He would treat them as his equals while discussing scientific matters. It was his habit to go round the laboratory every morning meeting each student, discussing the progress of his work and often suggesting new ideas. He would give free expression to his joy when a new result was brought to his notice. In his public lectures, he would refer to his students by name and talk about their work. All this was a thrilling experience to young students and a powerful incentive for sustained hard work and endeavour. A unique rapport was thus established between Professor and his students.

Professor encouraged his students to develop capacity for clear talk and exposition. He often remarked that one should be able to think on one's feet. His talks and lectures were always scintillating with new ideas and fresh outlook. The concept of the corrugated wave-front which is the basis of the famous Raman–Nath theory of the diffraction of light by ultrasonic waves came to him in a flash of intuition in the course of a talk.

Professor deprecated blind imitation and repetition of the ideas of others. "Let us think and do something original instead of browsing in Prof. Debye's backyard" was his characteristic remark on an occasion when someone was presenting the results of his study on the dielectric constants of liquids.

My work under Professor was concerned with the molecular scattering of light and the Raman Effect. He was still very much interested in problems relating to classical scattering of light, interest in which had some what waned with discovery of the Raman Effect and the vast new vistas of research it opened up. I began my work on Raman Effect by photographing the Raman Spectrum of a small sample of heavy water which had been presented to Professor from Norway. He was delighted to see the spectrum and the large frequency shift of the vibration bands as compared with those of ordinary water.

Professor recognised that quick publication of results was an essential part of scientific research. This was a great stimulus to young workers. He was free and generous with his ideas and would himself correct and revise manuscripts of papers which his students took to him. *The Proceedings of the Indian Academy of Sciences* constituted the forum for most of the publications from Professor's laboratory.

The range of Professor's scientific interests was amazing. He had working under him at the same time students of physics, mathematics, physical chemistry, organic and inorganic chemistry and even geology, all of whom received his direction and guidance on the problems on which they were working. Scattering of light and the Raman Effect, colloid optics, theory of molecular vibrations, experimental and theoretical studies on the diffraction of light by acoustic waves of ultrasonic and hypersonic frequencies, electrical and magnetic anisotropy of substances, X-ray diffraction by crystals and liquids, structure and properties of diamond, vibration of membranes, origin of the colours of shells and plumage of birds were among the topics on which studies were being pursued by Professor and his students during my stay with him, leading to a large stream of research papers.

Generations of students have passed through the portals of Professor Raman's laboratories inspired by the radiance of his genius and scintillating personality and carrying with them far and wide his message of science and zeal for scientific research which they have tried to spread around them. This is one of his greatest contributions to Indian Science apart from his own great discoveries and contributions which rank him among the immortals of science.

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MY PROFESSOR*

N. S. NAGENDRA NATH
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It was just a happy and unforgettable event in my life that I met my Professor by sheer accident who had just joined the Indian Institute of Science as its Director and Professor of Physics, and I had gone to the Institute to secure admission in the Electrical Technology Department. When I was leaving the Department after securing admission, I said to myself, why not meet the Nobel Laureate on the plea of becoming his research scholar ! I had no hope that I would get admission in the Physics Department as a research scholar as I had graduated in mathematics. After a thorough interview lasting till the evening, he stood up and patted me and said that I could join the Department as his research scholar. I then told him my plight that I had already secured admission in the E. T. Department. He appeared to feel annoyed but then he said that I had to give up the admission in the E. T. Dapartment. I said that I would very gladly do so and join his Department. I was overwhelmed. by his kindness and generosity, and academic outlook which appeared to me like a mountain peak and I had chosen my *guru* from that moment.

The new Department of Physics had to be organised. The work that was entrusted to me was to prepare a list of books in Physics and Mathematics for the library. I prepared a long list which contained quite a number of books in the purest of Pure Mathematics which could only be procured from Kohlers Antiquarium in Germany. I had thought that the Professor would make his own selection from my list, but he simply dittoed the list and said that I had to prepare additional lists from time to time.

One day I picked up enough courage to tell him that a teacher of mine who was exceptionally brilliant in Pure Mathematics was at that moment without a job. He said ; "Do you really think so ?" "Yes," I replied, "All right, ask him to meet me," he said. The teacher met him and he was taken as a research scholar, Professor observed no water-tight compartments between one subject and another and this was to be seen in his lectures drawing analogies from one discipline to another.

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*This article by Late Professor Nath was also a part of the Raman Memorial Issue of Current Science (1971).

I do not remember a single occasion when Professor talked with me anything other than academic problems. When we were discussing some problem, he received the day's dak which contained a letter from Professor V. M. Goldtschmidt that he would accept an assignment in the Institute. A letter from a top scientist in the Siemens had also been received indicating that he too would accept an assignment in the Institute. Professor was perhaps in contact with a number of others also.

His encouragement to beginners was unsurpassed. One day when I told him that I had found the explanation of the Raman line in diamond which had been mentioned by him as an outstanding problem in his Nobel address, he asked me what it was. I said that the Raman line was to be attributed to the mutual vibration of the two face-centred lattices composing the diamond lattice ; he simply yelled out, "you are right, you are right," and insisted that the research paper should be immediately written up. He was in ecstasy over this work. I found myself elected to the Fellowship of the Indian Academy of Sciences at the age of 23 years of which Professor had given no inkling to me.

One day, Parthasarathy was to give an account of the determination of the velocity of sound in organic liquids by the method of diffraction of light by ultrasonic waves. Hardly had he finished the description of the experimental set-up, than Professor raised the query —What is the number of diffraction orders expected on the basis of Brillouin's theory ?—The reply was two first orders of weak intensity. What was the fact, was the next query. A number of diffraction orders not in agreement with the theory. Professor went to the board and said that the theory should be developed in a different way. A sound wave creates compressions and rarefactions. A light beam would be slowed in the region of compressions and it would move faster in the region of rarefactions, and so a plane wavefront would become a corrugated wavefront like a zinc sheet used for building purposes. Professor said that an analysis of this corrugated wavefront would explain the unexplained results. When I went to him next day giving an explanation of the results on the basis of his ideas. he said it was all correct and that started a series of papers by him and myself which has come to be known in literature as Raman-Nath Theory, Though his outlook was essentially that of an experimental physicist, he would insist on the physical significance of every theoretical result. He had a stock in trade of certain physical results and he would liberally draw on them to explain results in a different subject altogether. Once Professor Max Born exclaimed, "He leaps over Mathematics.'

In November 1969, he and Lady Lokasundari Raman were graciously pleased to attend the marriage reception of my daughter. Professor drew me aside outside the reception hall and told me for nearly half-an-hour that his latest problem was to give a proper theory of earthquakes. The present theories were based on models which were highly deficient as they did not properly take into account the shape of the earth and the wave nature of the disturbance.

The blue of the sky, the blue of the sea, the colours of shells, the colours of flowers, the music of pianoforte string, the music of the Indian musical drum, molecular vibrations, diamond and its properties, crystals, nature of vision, make a gamut of beautiful things which he pursued, and so long as these beautiful things are there, Professor's name will always be there to guide further work. Truly it can be said of his motto in life—

'Beauty is truth, truth beauty'—that is all
Ye know on earth and all ye need to know.
—Keats

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The leader is one who, out of culture, brings simplicity; out of discord, harmony, and out of difficulty, opportunity.

— A! Einstein

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"Destiny is not a matter of chance; it is a matter of choice. It is not a thing to be waited for; it is a thing to be achieved"

— W. J. Bryan

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PROF. RAMAN ON THE RAMAN RESEARCH INSTITUTE

S. RAMASESHAN
National Aeroanutical Laboratory, Bangalore—17

Several times Prof. Raman has talked to me of the future of Raman Research Institute. He did this again between the 10th and 19th of November, only a few days before he died. I thought it may be worthwhile to record some of his thoughts which I noted down at that time. They are almost in his own words.

"The Raman Research Institute was created by me in 1948 to provide a place in which I could continue my studies in an atmosphere more conducive to pure research than that found in most scientific institutions. To me the pursuit of science has been an aesthetic and joyous experience. The Institute has been to me a haven where I could carry on my highly personal research work.

"This personal character of the Raman Research Institute should obviously change after me. It must blossom into a great centre of learning embracing many branches of science. Scientists from different parts of India and from all over the world must be attracted to it.

"The foundations of such a centre have already been laid. With its beautiful gardens, large libraries and extensive museums. I feel that the Institute offers a perfect nucleus for the growth of a centre of higher learning.

"I have always felt that science can only flower out when there is an internal urge, It cannot thrive under external pressures. I strongly believe that fundamental science cannot be driven by instructional, industrial, governmental or military pressures. This was the reason why I decided, as far as possible, not to accept money from Government.

"I am a very practical man and I am practical enough to see that it would not be possible for others to run or to grow a good institution without funds. I have bequeathed all my property to the Institute. Unfortunately, this may not be sufficient for the growth of this centre of learning. I therefore, will not put it as a condition that no Governmental funds should be accepted by the Institute. I would, however, strongly urge taking only funds that have no strings attached.

"The full potential of this centre of learning can only be achieved by exceptional leadership. Among the many qualities called for in a person who assumes this responsibilty are scientific integrity, vision, receptiveness to new ideas and the enlightened outlook to let younger people grow unhindered to their full height. If these qualities can also be combined with the scientific reputation acquired by significant personal contributions in a chosen field of endeavour one has the leader who is likely to succeed in developing the Institute and incidentally rendering the nation a service. Any person who assumes the responsibility of running the Institute must have full control of the laboratories, libraries, workshops and other facilities. He must be empowered to acquire and dispense money in the name of the Institute. He must have powers to appoint or terminate the services of personnel required for the running of the Institute. Nothing is so detrimental to the growth of science in a institution than the existence of dead-wood floating aimlessly which cannot participate in the scientific growth of an institute."

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MY ASSOCIATION WITH PROF. C. V. RAMAN

D. D. PANT
D. S. B. College, Nainital

I joined the Indian Institute of Science, Bangalore, during the turbulent days of August-September 1942. It took me 5 days to reach Bangalore by train from Banaras. I was staying with Prof. R. K. Asundi after my M. Sc. in Physics in 1942 in the hope that I shall be able to start my research with him. But since facilities at Banaras were meagre Prof. Asundi advised me to go to Prof. Raman who was kind enough to admit me to his group. My first meeting with him was in his office where he suggested that I should work on the Photoconductive Properties of diamond. He had, during those days, undertaken a comprehensive study of all properties of various types of diamonds like x-ray, Fluorescence, Raman Effect, Photoconductivity, Magnetism etc. He had a large collection of diamonds purchased from his own money. My first meeting with him inspired in me a mixture of awe and respect which in course of time, as I shall narrate later on, turned into great respect and affection. Behind his gruff manner lay a kind person with deep appreciation for finer human values.

Since the whole of India was in turmoil in those days, the students of Indian Institute of Science, one morning, went to Raman to request him to abstain from work. Raman usually came on his cycle—as petrol was not easily available—at 6 'O-clock in the morning. Raman faced them and with his brilliant rhetoric began to explain about his current interest in the theory of specific heat, and its importance for the prestige of the nation. He argued with them that he himself was a great nationalist and had refused to help the British Government by turning down their request, unlike other scientists, to work for war projects. The students still persisted in their request. But Raman had an uncanny gift to quick homour. His manner of pulling up the collar of his coat, standing erect and use of a phrase "You know what I mean" were so effective that they often created wonders. This time he stood out, pulled the collar and cajoled them by saying that the only way he can bring laurels to the country was by devoting his entire time to Science and added, "you know in foreign countries they know only two persons, one is Mahatma Gandhi and the other you know what I mean." The students enjoyed the humour and left him to do his work.

His popular lectures on Science were highly illuminating and witty. Nobody so far has equalled him in this art. Once delivering a popular lecture at B. H. U. where he was an honorary professor, he explained the essence of the second law of thermodynamics in the following way : "Take a bucket of hot water and a bucket of cold water, mix them in a third bucket, now separate out the hot molecules and put them in first bucket and the cold molecules in the second bucket." As is known that second law of thermodynamics does not violate the energy conservation in any process, but something else called entropy increases which cannot be reversed, You could not have a better example of explaining the concept of entropy than this. You could hear in his public lectures, the whole audience, even laymen, all roaring in laughter. Once delivering a lecture on his theory of specific heat, and criticising the older theories of Born and Debye, he saw that some members of the audience sitting in front row were laughing, he could quickly guess that his trousers were sliding and he was pulling them up. He characteristically said, "Ladies and gentlemen, the theories of Born and Debye are like loose-trousers, they do not fit in well." The hall roared with laughter. There are numerous stories of his wit and apt humour fitting a situation. Prof. Birbal Sahni who was also a renowned scientist and was earlier Prof. of Botany at B. H. U. and later went away to Lucknow University was a friend of Prof. Raman. Once Sahni who was a typical Lucknow's aristocrat, was showing Raman round his department and at each door step after opening the door would courteously say "after you,'. When this process was repeated a number of times, Raman turned back and asked Sahni, "Well Sahni why are you after me ?"

In these reminescences, I shall mostly talk about my personal encounters with Raman than describe his scientific work, as the latter requires no description. Working with him you could feel how enthusiastic he got even if you had discovered a minute thing and would praise you in the public for whatever sincerity of purpose you had shown. His personal example of hard work and devotion was an inspiration to all his students. His candour, fearlessness and love for honesty and truth cannot be matched; at least I have rarely come across persons having these qualities to the degree which Prof. Raman had. He had great love to communicate new ideas and was quite undiplomatic and transparent. That he was a great humanist and a kind person, dawned on me in course of my stay with him. Once in a seminar held in 1943 during the war on Science and its Applications which was attended by some British Army officers, Homi Bhabha and others, he took up the position that science should not produce anything which can be used for destructive purposes. Science should just be a study of nature. Bhabha was of the view, if the science is misused, it is the fault of the user, and not of science. If you make a knife, it has to be used for cutting fruits but not for cutting throats. Science is not at fault in making a knife but it is the fault of man if he misuses the science which really is meant for the convenience of humanity. Raman in his eloquent manner contested this claim and did not want to make any distinction between the good use and bad use of science and said, "let there be no knife for good or bad, let us return to the days of Buddha and Christ" I could not quite understand the position taken by Raman then. But several years later, at this point of time when the atom bomb is staring at us in the face, for complete annihilation of all form of life on this planet, I recall the words of Raman, uttered during the seminar. They give me a new perspective of his personality. I now understand why he took such a strong position then.. Science can answer 'how' and even 'why'. Can it answer what "ought" to be ? In the Raman Research Institute, he has built a beautiful museum of minerals, sea shells, etc. which I would recommend to any visitor to his institute to see and read also a quotation which hangs in a corner. It reads, "It is not through science that human miseries will be eliminated, but it is through persons like Buddha, Christ and Gandhi. who can influence the human conduct that humanity can be saved".

I stayed at Bangalore for nearly 2 years when I had to take up a job at Agra. I went to Prof. Raman to see if he could recommend me fot the job. My work was going on well and probably he expected me to stay on longer. I explained my difficulties and family-circumstances and he asked whether I was married. When I answered in the affirmative, he quickly asked "why did you marry." Then he himself said he knew the circumstances in the Indian family and agreed to recommend me for the job. But before that he said he could offer me a job in the Meteorological Department where the salary was about 4 times the salary I would get at Agra College as Lecturer in Physics. I used to wear khadi and this was a job connected with war. I declined saying that I wanted to be a teacher. He then uttered the prophetic words, "you will always remain poor." He advised me that during the summer vacation I should return to Bangalore and complete my work for the Doctorate degree and that he would continue giving me the Institute Scholarship during my stay at Bangalore during the summers. It was rather extraordinary for him to go into personal details and I felt greatly obliged to him. Next summer when I went to Bangalore, India Government were sending about 500 students abroad (1945) and Raman asked me whether I would like to go abroad. Again I showed my inability stating that it would be improper for me to leave Agra College where I had just served for 9 months. I could see that he liked this attitude of mine and later talked about my views to Dr. N. K. Sethi of Agra College. I got my Doctorate in 1949 when Prof. Raman gave a talk to the general public in the Amphitheatre of B. H. U. on Entropy about which mention has already been made, I met him with a gap of few years several times but two of my meetings with him in the Raman's Institute when he had shifted after his retirement are memorable. At the newly built Institute, he had shifted his line of research from theory of solids to study of Human vision. This was an entirely new field of research work for a Physicist and Raman wanted to complete the work started by Newton, Helmholtz and Young. Many physicists did not like his indulging in this type of research. It appears Sir William Lawrence Bragg had come to India, and met him at the Institute. I was in Bangalore after a few days of this meeting and wanted to meet Prof. Raman and I was promptly given time to meet him. After asking me as to what I was doing at Nainital where I had shifted from Agra, he began to narrate the story of his encounter with Sir Lawrence. In his characteristic way, he narrated that Sir Lawrence wanted him to continue work on x-rays and leave working on the theory of vision. "I replied", he said. "Sir Lawrence do you mean to say, I should not chase the lions (Newton. Helmholtz and Young) and instead chase jackals." As everybody knows, Sir Lawrence Bragg was a Nobel prize winner in x-rays. Then, he began to tell about his researches on colour of flowers and so on and I alongwith Prof. S. C. Sircar of Calcutta spent nearly two hours with him examining the spectra of flowers with hand-spectroscope. (Since then I ask my students to use a direct vision spectroscope to examine street lights, flowers, sun set etc.) Many things were astounding; inspite of widely different colours of the flowers, there always appeared an absorption band around 580 nm. He had a theory for this which I forget now. He also narrated how he comes out of his bed-room at 12'0 clock in the starry night, so that he could adapt his vision to one millionth of the intensity of light obtained during the day and works out some experiments pertaining to theory of vision. He had fallen down the previous night as a water pipe was lying in the garden in which he had got entangled and had a swollen knee. He was then about 78.

The last I saw him was a few months before he died. He was alone in the Raman Research Institute. He had only Mr. Padmanabhan as his student, Secretary and companion. He asked me to sit down on a stool in the darkroom in which he was making some observation with the help of Padmanabhan. After some minutes of usual exuberance about the observation he made (to which I was acustomed from earlier days) he turned towards me and this time did not ask as to how I was and what I was doing. He straight away asked me whether I had seen photons. When I replied in the negative he, with youthful vigour, said "come on I shall show you." He was 82 then, the enthusiasm and the energy was remarkable. I was led to another room and asked to sit on a stool. The room had a small hole in the wall, diffuse light entered through the hole on a mosaic plastic screen which diffused further on to another mosaic screen from where the light, if any, diffused into the room. The room was then closed and black curtains pulled. I was asked to close my eyes for two minutes and then open them. On my opening the eyes, he asked me whether I see anything. I said, "yes Sir, I do see the photons." They were like tiny sparks entering the eye at irregular intervals. I had never expected that Prof. Raman at that old age would devise an experiment just for the fun of showing it to ordinary people. I was overjoyed and expressed my gratitude to him. He laughed his suppressed laughter and then asked me "why do you use red-light for danger signals ?". I replied because red light is scatteredless than green light. He said, this is only partially true. Actually the full explanation should include "Eye is more sensitive to red light than to green light when the total intensity of light is low. But, if the intensity of light is moderate or high, eye is sensitive more to the green light." Before I could thank him he again said, "come on I will show you" and then started another experiment. He had a constant deviation spectrograph with a ground glass plate on one side and ordinary filament lamp near the slit. On the ground glass plate you could see the continuous spectrum and visually the green would appear more intenes than the red. But as the intensity of light was diminished by narrowing the slit, the intensity became very low, one saw, the red part of the spectrum appearing more bright than the green When I expressed my pleasure over this demonstration of the phenomenon, Prof. Raman got immensely pleased and I could see that in disseminating knowledge even to a single person like me, he found some sort of fulfilment.

It was time to leave. He had finished his job and there was no time for superfluous talk. I folded my hands more in affection than mere respect and bade him good bye. I never imagined, inspite of his ripe age, that would be my last glimpse of him I have. On the way to the guest house at the Indian Institute of Science, I was marvelling about the motivating force which made Raman to spend so much time in demonstrating the two phenomenon to me. Possibly like all great teachers be derived pleasure in communicating ideas in a way which would malke permanent impression on memory. I have since then asked many physicists about this and the answers are varied. Any way, I am thankful to the great master for all what I received from him–not only in Scicnce but also in human values. Bernard Shaw once said of Mahatma Gandhi, "....Why, that is not a man, that is a phenomenon." Perhaps I can repeat and say Raman was a phenomenon.

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"Knowledge is like a sphere in space; the greater its volume, the greater is its contact with the unknown"

— Pascal (often quoted by Professor Raman)

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"You see things and say why ? But I dream things that never were, and I say why not ?"

— Bernard Shaw

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THE DISCOVERY OF THE RAMAN EFFECT, REMINISCENCES OF SIR C. V. RAMAN*

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What was called "A New Radiation" by the discoverer himself at the time he discovered it and what has since then come to be known as "The Raman Effect" was first observed by Professor Raman at Calcutta in the laboratories of the Indian Association for the Cultivation of Science at 210, Bow Bazar street, during the evening hours of February 28, 1928. The first public annoucement was made in a daily newspaper of Calcutta dated February 29. In addition to a brief and technically inadequate newspaper account of the discovery, the news item stated that Professor Raman will deliver a lecture demonstrating the phenomenon first at Bangalore on March 16, 1928. Following this announcement. Professor Raman delivered an address to the South Indian Association at Bangalore on March 16, 1928 under the title "A New Radiation".

Even at the outset, I would like to mention what I regard as the noteworthy features characterising this discovery. These have been gathered by me to a small extent from published material and to a large extent from personal knowledge and assessment. Firstly, the discovery was by no means the result of an accidental stumbling into an unexpected observation. Well thought out experimental work on different aspects of light scattering by Professor Raman and several of his Indian coworkers spreading over several years at that time was the forerunner of the main discovery. Secondly, the equipment used for making the final observation consisted of a mercury arc lamp, a large aperture glass condenser, a glass flask containing clear and purified liquid benzene and a direct vision pocket spectroscope, total cost of all of which would have been around Rs. 200/-. Thirdly, in all the early work relating to light-scattering, the use of sun light, a plentiful resource in the country where Professor Raman did work was fully exploited. Raman often used to say "make full use of what you have, before you ask for what you do not have". This brings out clearly Raman's attitude to scientific research contained in an oft quoted statement of his, namely, "The essence of science is independent thinking, hard work and not equipment". Great discoveries always appear incredibly simple, but alas only after some individual has made the discovery.

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*This is adapted from a talk delivered at the conference celebrating 50th anniversary of the discovery of Raman Effect.

It is best to quote here what Professor Raman himself wrote, nearly 40 years after the discovery, about how he was led to make the discovery.

"Later, I became aware of the remarkably brilliant monochromatic illumination which could be obtained by the aid of the commercially available mercury arcs sealed in quartz tubes. Towards the end of February 1928, I took the decision to make use of such lamps for all further studies in the field of light scattering. The success which attended this forward step was immediate and highly gratifying. Experience in working with sunlight indicated the techniques necessary for the observation of extremely weak phenomena, viz., the rigorous exclusion of stray light and the conditioning of the observer's vision by a prolonged stay in darkness. On setting up the apparatus and making these preparations, I found that the light of the mercury arc diffused by various materials when examined through a direct vision spectroscope showed the presence, besides the lines of mercury, also of other lines the positions of which varied with the substances under study. Amongst the numerous materials thus examined was a large block of clear ice. This showed sharp displaced lines in the scattered light in approximately same positions as the rather diffuse bands observed with pure water. Within a few days of the discovery, photographic spectra were successfully recorded in which the additional lines showed up very clearly".

The tenacity with which Raman proceeded to establish what he then termed the "Universality of the Phenomenon" is worth recalling. Within a few days or weeks of the first observation in liquid benzene, he got observations extended to other states of matter like ice representing solids, ether vapour representing gases and so on.

The discovery soon became one of great significance to men of science working in diverse areas like physics, chemistry and so on, that the Raman Effect studies began gaining adherents in many countries of the world. In 1948, there was a special celebration of the twentieth anniversary of the discovery, organised in the Science Faculty of the University of Bordeaux in France.

India celebrated the silver jubilee of the discovery of the Raman Effect in 1953. Special meetings were held in many places and glowing tributes were paid to the scientific achievements of Raman. The contents of a message given by Professor Albert Einstein on that occasion is of great significance to me. It is on record that when Einstein was approached by a press correspondent and asked to give a message, he said "In one respect, at any rate, modern physics can serve as a model. The progress of empirical knowledge and of the basic ideas about the structure of matter and about elementary phenomena is, indeed, an international process, in which all nations take part. Thus C. V. Raman was the first to recognise and demonstrate that the energy of a photon can undergo a partial transformation within matter. I still recall vividly the deep impression that this discovery made on all of us who at the time attended the physics colloquium in Berlin. Let us watch that at least the brotherhood of inquiry does not fall victim to the monster Politics, even though the BIGS do not set a shining example".

In the search for new materials of interest, wherein Raman Effect could be studied, the manner in which Raman picked up the case of diamond and the story of how a study of its remarkable physical properties and of its structure came to be a fascinating and life-long involvement for him are both interesting and illuminating.

Immediately after the discovery, Raman noticed quite casually that his younger brother was wearing a wedding ring with a diamond on it and made some provocative remarks. The latter, who just then graduated in physics and was a research student made a brief spectroscopic examination and found that diamond exhibits a strong and sharp Raman line corresponding to the now well known frequency shift of 1332. This result was immediately confirmed by me, repeating the experiment at Calcutta, in Raman's laboratory. It was further observed that besides this sharp line, a complex luminescence spectrum, the principal feature of which was a well defined band at 4155 A. U. was also present. With these results as the starting point, Raman built up his interest in diamonds to such an extent in a few years, that at one time, every student working with him was engaged in studying one aspect or other of the properties of diamond.

Quite early in this process, he borrowed one big piece (140 carats) for me from the collection of the then wealthy Indian Maharajah's. The loan was for a limited period and against a security bond for a fairly large sum of money which he had to sign before borrowing it. When he put this rare diamond in my hand for intensive spectroscopic studies in the following 48 hours, he cautioned me to be careful and not lose it and told me how history is replete with stories of professional thieves following great Indian diamonds to stumble on the right opportunity for whisking them away from the owners.

For two nights, I slept under the spectrograph with protecting glasses on my eyes. We got some very exciting results and my paper was immediately published. The results were abstracted in Science abstracts under the title "Raman spectrum of Diamond." Within brackets, the abstractor noted that the weight of the diamond used was 140 carats and to show his surprise, he inserted three or four exclamation marks. He could not believe that a poor Indian scientist could handle a diamond of that large size, Raman's interest in diamonds never waned and it is interesting to recall that so recently as a couple of years before his death, he spent a lot of time studying the geography and the geology of the Krishna valley and of the rivers that flow in and around it because it has. been known that at one time 60,000 people engaged in diamond mining operation in that area.

I had the privilege of being one of his collaborators at the time when he was awarded the Nobel prize for physics. I vividly recall his reactions when I communicated to him the first news of the award after knowing it on telephone from one of the Indian news agencies in Calcutta. He asked if he was the sole awardee or was he to share the bed with other strangers.

To hear Professor Raman expounding physics to a general audience was indeed a most exhilarating educational experience.

I can never forget and never fail to recall the generous affection he used to show to his associates and to me in particular and when he did it, he was transparently sincere and straight–forward, humane and humorous, wise and witty.

RAMAN SPECTROSCOPY IN EUROPE FOR THE PAST FIFTY YEARS*

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Introduction :

It is a great honour for me to be invited to share with Professor S. Bhagavantam and Professor R. C. Lord, the presentation of the history of the development of the Raman effect at this opening session of the Sixth International Conference on Raman Spectroscopy, which celebrates the fiftieth anniversary of Raman's classic discovery. It is particularly pleasing to be giving this address in India, Raman's native land, and in Bangalore where he did much of his work.

The development of the Raman effect over the fifty years since its discovery can be divided into three distinct periods: 1928-1939; 1940-1963; and 1964-1978. I shall devote the greater part of my talk to the earliest period with which you will be least acquainted,

The Period 1928-1939 :

You have heard from Professor Bhagavantam how in 1928 Sir C. V. Raman came to discover the effect which is named after him. In 1978, with quantum theory firmly established, we are used to the immediate interpretation of any new spectroscopic phenomenon; and with modern rapid methods of communication we are accustomed to seeing any new scientific discovery rapidly exploited.

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*This is adapted from a talk delivered at the conference celebrating the 50th anniversary of the discovery of the Raman Effect.

However it is rather more remarkable that, in 1928. when the quantum theory was new and communication less rapid, the fundamental significance of the newly discovered Raman effect should have been so quickly grasped and its potential in chemistry and physics so rapidly realised. By the end of 1928 about 70 papers on the Raman effect had been published; and by the end of 1929, the number of published papers had grown to over 200. This rate of publication continued unabated throughout the period under consideration, and by 1939 the total of published papers had risen to over 1800 and the Raman spectra of over 2500 compounds had been reported.

Anything approaching a complete survey of such a vast amount of material is quite impracticable. All I can hope to do is to try and recapture something of the atmosphere of this period, particularly the very early years.

I will begin with the 150 papers involving some 100 authors published in the period March 1928–July 1929. The first two papers to be published after Raman and Krishnan's letter to *Nature* published on March 31st 1928 came from France. Y, Rocard in a contribution to *Comptes Rendus* read to the French Academy of Sciences on April 23rd 1928, discussed several aspects of Raman's work and *inter alia* suggested that diffuseness of the lines found in the spectrum of benzene might be due to such causes as intermolecular fields. J. Cabannes in a contribution to *Comptes Rendus* read on April 30th 1928, presented a classical theory of the Raman effect considered as an amplitude modulation of the induced dipole by molecular vibrations or rotations–a mechanism which Cabannes called "optical beating", At the meeting of the French Academy of Sciences on June 4th 1928 A. Cotton pointed out that there were some similarities between Raman scattering and the resonance scattering discovered by R. W. Wood, and at the same meeting J. Cabannes and P. Daure reported measurements of the breadth of the Rayleigh line produced by scattering from liquids like benzene and ether and correctly suggested that this arose from molecular rotations. On June 25th 1928,

P. Daure described to the French Academy of Sciences quite detailed studies of the Raman spectra of liquids, liquid mixtures and aqueous solutions.

This extraordinarily rapid development of Raman spectroscopy in France came about because conditions were particularly favourable for its study. J. Cabannes had been engaged on experimental studies of the scattering of light by gases since 1913, and the French optical industry under J. Cojan's leadership was beginning to produce excellent prism spectrographs with photographic detection eminently suitable for Raman spectroscopy,

But immediate developments were in progress elsewhere too. On May 6th 1928, G Landsberg and L. Mandelstam, in Moscow submitted an important paper to *Die Naturwissenschaften* which was published on July 13th. This paper reported the first Raman study of a crystal, quartz. Although this work was carried out independently of the work in India the authors acknowledged that they had seen Raman and Krishnan's letter in *Nature* before submitting their own communication.

In the first review article on the subject, published in August 1928 in *Die Naturwissenschaften* P. Pringsheim, in Berlin, christened the new light scattering effect, the Raman efiect, and in the same issue of this journal, A. Smekal, in Vienna, drew attention to his earlier paper published in 1923 on the quantum theory of dispersion. In this paper Smekal had pointed out that light scattering might be accompanied by a change in the energy level of the scattering system so that the scattered radiation would differ from the incident radiation by characteristic frequencies of the system. Smekal's prediction of the Raman effect, five years before its observation, was so unambiguous that for some time, certainly in Austria, the name Smekal-Raman effect was used.

In the issue of *Die Naturwissenschaften* for August 24th 1928, M. Born explained that the relative intensities of Stokes and anti Stokes Raman lines could be correctly accounted for by quantum theory. This topic was also the subject of the first contribution to Raman spectroscopy from Italy, a paper by A, Carelli published in *Atti della Reale Accademia Nazianale*, Rome in August 1928.

The first contribution to Raman spectroscopy from Great Britain was a note published in *Nature* in December 1928 on the polarization properties of the Raman lines of carbon tetrachloride. The authors were T. C. Keeley, N. R. Hall and F. A. Lindemann. F. A. Lindemann who was professor of physics at Oxford for many years, does not appear to have made any further contributions to Raman spectroscopy, but apart from a distinguished career in physics generally he also achieved fame as "The Prof." scientific adviser to Winston Churchill, and was subsequently ennobled as Lord Cherwell.

The first contribution from Japan was that of M. Kimura and Y. Uchida who described work on the Raman spectra of xylene, calcite water and an aqueous solution of neodymium ammonium nitrate in a paper published in the Japanese *Journal of Physics* at the end of 1928.

In the issue of *Nature*, February 2nd 1929, J. C. Mc Lennan and J.H. Mcleod published an account of studies of the Raman effect of *liquid* oxygen, nitrogen and hydrogen. Their results for hydrogen led them to conclude that in hydrogen at low temperatures there are two sets of molecules, one set in the zero vibrational, zero rotational state and the other set in the zero vibrational, first rotational state. They also noted that the Raman effect can be observed in homopolar molecules and that two quantum rotational transitions occur in Raman scattering.

In the next issue of *Nature*, February 9th 1929, F. Rasetti, in Italy, reported the vibrational Raman spectra of carbon monoxide and carbon dioxide. He noted that for carbon monoxide the vibrational frequency observed in the Raman spectrum agreed with that observed in the infra-red spectrum, but for carbon dioxide none of the infra-red frequencies were found in the Raman spectrum.

The first of a series of papers by A. Dadieu and K.W.F. Kohlrausch at Graz, Austria, on the Raman spectra of organic compounds appeared in *Sitzungberichte der Akademie der Wissenschaften*, Wien, early in 1929. The spectra of a series of fatty acids and their esters were reported and the relationship between Raman shifts and particular chemical bonds discussed.

During 1929 F. Rasetti published several classic papers dealing with both the theory and the experimental observation of rotational Raman spectra of diatomic gases. For example in a paper in the *Proceedings of the National Academy of Sciences* for June 1929, Rasetti reported the rotational Raman spectra of oxygen and nitrogen using mercury resonance radiation at 2536 A obtained from a specially constructed quartz mercury arc. Good spectra were obtained with exposures of 60–120 hours. From the results for oxygen Rasetti deduced that only *odd* rotational levels are populated. The spectra for nitrogen showed an intensity alternation, with the rotational lines arising from transitions between *even* states *strong*, and these arising from transitions between *odd* states *weak*. In July 1929 Rasetti reported the first observation of an electronic transition in the Raman effect arising from the transition between the $^2\pi_{1/2}$ and $^2\pi_{3/2}$ states of NO which are separated by 124 cm^{-1} δ.

In the issue of *Zeitschrift fur Physik* dated May 1929, G.B. Bonino at Bologna, Italy reported the Raman spectra of $C_2H_2Cl_2$ and $C_2H_2Cl_4$ and discussed their relation to the infra-red spectra. During the rest of 1929 there appeared a number of papers on the Raman spectra of organic compounds by Bonino and his co-workers.

In the issue of *Comptes Rendus* for July lst 1929 we find the first contribution to Raman spectroscopy from Poland, a report by W. Czapska of the Raman spectra of *o*, *m* and *p* xylenes. And in a July issue of *Nature* there appeared the first contribution from Denmark, a communication by A, Langseth on the relation between Raman spectra and ultra–violet absorption.

It is interesting to turn next to the report of a General Discussion of the Faraday Society held at Bristol in September 1929. The subject was

Molecular Spectra and Molecular Structure, and a substantial amount of the meeting was devoted to the Raman effect. Raman himself, now knighted, gave one of the plenary lectures and important papers were contributed by, amongst others, R. W. Wood, J. Mclennan, J. Cabannes, P. Daure, G. B. Bonino and A. C. Menzies. Menzies, contribution covered studies of the polarization of Raman lines in liquids and the first observation of Raman scattering from a powder, KNO_3.

This must have been a memorable Faraday meeting for, in addition to the distinguished Raman spectroscopists just mentioned, there were also present J. E. Lennard Jones, R. S. Mulliken, F. Hund, R. T. Birge, G. Herzberg, V. Henri, G. H. Dieke, W. Jevons, R. Mecke, R. M. Badger, J. Lecomte and E. K. Rideal. One paper, and several contributions to the discussion came from one of A.C. Menzies, former research students C. P. Snow, but although Snow made several interesting contributions to Raman spectroscopy at this time, he was already thinking of another career as a novelist–a career in which he subsequently achieved fame as the author of a well known series of novels dealing with science and scientists in academic and government circles.

In 1931, Professor Bhagavantam surveyed and classified by subject mattet some 350 papers on the Raman effect published between March 1928 and June 1930. The already wide-ranging applications of the Raman effect are illustrated by the fact thar *twenty four* different subject headings were neoessary in Bhagavantam's classification : Experimental Technique; Character of the lines; Continuous Spectrum; Intensity; Polarization; Rotation and Vibration-Rotation Spectra; Relation to Infra-red Absorption; Relation to Ultra-violet Absorption; Resonance Radiation, Fluorescence and Phosphorescence; Crystals and Relation to Crystal Structure; Effect of Change of State; Effect of Solution and Electrolytic Dissociatian; Effect of Molecular Association and Polymerisation; Liquids and Liquid Mixtures; Influence of Temperature and Pressure; Relation to Molecular Structure and Specific Heat; Chemical Binding and Nature of Valency; Relation to Chemical Constitution; Relation to Paramagnetism and Electric Polarity; Relation to Photo-conductivity and Photochemical Dissociation; X-ray Analogue; Theory; Incoherence; Appearance in Emission and Absorption Spectra.

Other bibliographies of work in this period by Kohlrausch, by Sirkar, by Sirkar and Chakravarty and by Hibben, further testify to the lively interest in, and considerable importance of the Raman effect.

Initially, some aspects of the theory of the Raman effect. particularly selection rules, intensities and temperature effects were not fully understood, but the whole theory of the Raman effect was soon put on a secure footing by the brilliant work of G. Placzek which was brought together in his remarkable and justly famous 170 page article, *Rayleigh and Raman Scattering*. published in 1934. The full exploitation of Placzek's work was not possible at this time and indeed has only begun to be possible in recent years, especially as for as intensities, polarization phenomena and resonance effects are concerned.

A great deal of the work on Raman spectroscopy in this period was devoted to chemical problems.

I was privileged to get an insight into what the Raman effect meant to chemists, when in May of this year (1978), Professor Bonino described to me the tremendous excitement he felt one day in 1928 when he opened the March 31st issue of *Nature*,newly arrived in the library of the University of Bologna and realised that Raman's discovery would make essentially complete studies of vibrational spectra quite easy.

Not unexpectedly at this time vibrational Raman spectroscopy found great application in organic chemistry. As early as June 1931 K. W. F. Kohlrausch had published a classic book of 392 pages, *Der Smekal-Raman Effekt*, which listed characteristic frequencies and Raman spectra for many classes of organic compounds; by the end of 1935, some 726 papers ralating to 1370 organic compounds had appeared; and in 1937 the application of Raman spectroscopy to organic chemistry was the subject of a scholarly review by Professor Bonino.

Such results were of great importance in the development of valency theory in the thirties. These studies required an understanding of group theory and the mechanics of molecular vibrations and the necessary theoretical developments were made concurrently by L. Tisza, E. Wigner and E. B. Wilson.

Many structural problems in inorganic chemistry were also solved using vibrational Raman spectroscopy.

It is not possible to continue quoting examples in detail. I can only conclude my survey of this fruitful first period with a roll call of some of the distinguished contributors to Raman spectroscopy whose work has not been mentioned so for. E. F. Gross in Russia; G. B. B. M. Sutherland in Great Britain; M. de Hemptinne, C. Manneback and J. Duchesne in Belgium; H. Gerding in Holland; S. Mizushima and Y. Morino in Japan; R. Baer in Switzerland; A. Kastler, M. Delwaulle, F. Francois and M. Magat in France; W. Gerlach, C. Schaefer, F. Matossi, J. Goubeau and A. Simon in Germany; R. Manzoni-Ansidei in Italy.

The Period 1940-1963.

The first six years of this period saw a very marked reduction in research in Raman spectroscopy for reasons that are familiar to all of us. In 1948 Bordeaux in France was the venue for Le colloque International sur L. Effet Raman. The transactions of this meeting form a valuable survey of work during and immediately after the Second War. This meeting was attended by Sir C. V. Raman and M. Born and a fascinating part of this conference must have been the lively discussion regarding the relative merits of their two theories of the second order Raman effect in crystals.

After the war many spectroscopists were attracted to tnfra-red and microwave spectroscopy rather than Raman spectroscopy. Relatively powerful instrumentation became available to them and a wide range of problems could be tackled. By contrast, instrumental developments in Raman spectroscopy were much more modest in nature. As the problems grew more demanding the limitations of the available experimental techniques became more and more obvious. In particular the severe restrictions imposed by the mercury arc became increasingly evident despite the refined versions of the mercury arc introduced by the Toronto group.

The number of spectroscopists working in Raman spectroscopy during this period was therefore quite small. However they were a dedicated group and their work is particularly interesting for it shows that if the choice of problems is discerning, and the available experimental techniques are fully analysed and understood, excellent and valuable work can be done-underlining Raman's own philosophy "the essence of science is independent thinking, hard work and not equipment".

Today I can do no more than mention some of those who kept Raman spectroscopy alive during this period; L. A. Woodward and his school at Oxford, England, (applications to Inorganie Chemistry and vibrational intensities); A. C. Menzies, of Hilger and Watts, London, England, (Raman instrumentation); J. P. Mathieu and his school in Paris, France (study of crystals, leading *inter alia* to the discovery of Lo-To splitting); J. Brandmueller and his school at Munich, Germany; P. P. Shorygin, M. M. Sushchinsky, G. S. Landsberg, M. W. Wolkenstein and others in Russia (intensities, resonance effects and characteristic parameters in Raman spectra of organic compounds); the Liege school in Belgium, associated with the names of G. Duyckaerts, G. Michel and P. Tarte (Raman spectra of solids and quantitative applications of Raman spectroscopy); J, Morcillo in Madrid, Spain; H. Gerding in Amsterdam, Holland; S. Brodersen in Denmark; the Bologna school of G. B. Bonino; S. Mizushima and T. Simanouchi in Japan and so on.

The period 1964-Present.

The history of this period is quite well known to you all. It is a period which can be aptly described as the Renaissance of the Raman effect. This Renaissance is due in the main to the advent of the laser although developments in dispersing, detection and recording systems have also played their part. The laser is without doubt the long-sought-after source for the production of good quality Raman spectra from minute amounts of sample of almost any nature and the exploitation of the full potential of Raman spectroscopy. Also the laser has revealed new kinds of light scattering generically related to the Raman effect, like the stimulated Raman effect, the inverse Raman effect, the hyper Raman effect, and coherent anti-Stokes Raman scattering to name but some.

THE EARLY DAYS OF RAMAN SPECTROSCOPY IN THE UNITED STATES*

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The histoty of the Raman effect in the United States began for all practical purposes when R. W. Wood first read Raman and Krishnan's brief notice[1] in the March 21, 1928, issue of *Nature*, Wood, widely recognized for his work in light scattering, had discovered the phenomenon of resonance fluorescence in 1906 and thereafter devoted much attention to the optical arrangements for the spectroscopic study of scattered light. Wood probably read Raman and Krishnan's note in the library of the private research laboratory of Alfred Lee Loomis at Tuxedo park, New York, where he was spending the summer months of 1928, and he at once set about confirming their report.

It may be that Wood had already been alerted to the posibility of the existence of a shift in the wavelength of scattered monochromatic light by a personal communication from H. A. Kramers. Kramers is supposed to have written Wood, presumably in 1924 or 1925, to say that on the basis of the Kramers-Heisenberg dispersion theory[2], a small fraction of the incident rediation would be scattered with a shift in wavelength. Kramers supposedly estimated this fraction to be many orders of magnitude less than that of Rayleigh scattering and Wood is said to have replied that it would be hopeless to detect it in the presence of the much stronger Rayleigh radiation. The writer has not been able to confirm this story. Wood does not hint at it in any of his papers or in the 1934 edition of his "Physical Optics". A review of the Kramers file of correspondence at the Niels Bohr Library of physics shows no letters to or from Wood, and that library's rather uneven collection of Wood's correspondence is also non–contributory. Neither dose his published work support another legend to the effect that when Wood read Raman and Krishnan's note he checked his own file of spectroscopic plates of scattered light and found evidence of the Raman effect thereon.

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*This is adapted from a talk delivered at the conference celebrating 50th anniversary of the discovery of Raman Effect.

Wood's initial efforts were typically simple and *ad hoc*. We have an eye witness account by an expert in the theory of vibrational Raman spectra, E. Bright Wilson, Jr., who as a college undergraduate was working at the Loomis Laboratory in the summer of 1928. In Wilson's recollection[3], "Wood read the letter by Raman...and immediately went into the laboratory and improvised a setup to check the effect. As I remember it again, it was a quartz crystal for the substance all rigged up with clothespins and string and that sort of thing, and used a bucket full of solution for cooling and filtering the light, which then poured down over the quartz crystal. Everything was extremely jerry-built in a few hours but he got his spectrum and cabled off a note to *Nature*".

Despite the improvisations in his first experiments, in this note to *Nature*[4], he labelled the high-frequency shifts "anti-Stokes terms" and noted that their intensities in carbon tetrachloride were comparable to those of the Stokes lines, while in benzene and toluene, they were much more difficult to observe. However, in an extensive paper[5] posted on September 8 (shortly after his cable), he gives a great amount of valuable experimental detail, including reproductions of the spectra of 10 substances.

While Wood used the anti-Stokes designation in his first communication (it was standard language for investigators of fluorescence), it was also used simultaneously by Pringsheim. The latter was stimulated by Raman and Krishnan's note to write a masterly review of molecular light scattering, in which he placed Raman scattering in the correct context with respect to fluorescence[6]. This article, which seems to be the first specifically to name the Raman effect, includes the statement (writer's translation) "Thus one can scarcely doubt any longer that a new effect has really been found, which consequently should be called the Raman effect" (6, page 123).

Another "first usage" by Wood was his early employment of a diffraction grating to study Raman spectra. In a "Note on Raman Lines Under High Dispersion"[7], he describes the use of a 15-cm plane grating and a lens of 3-m focal length to examine the spectra of C_6H_6 and CCl_4.

The first clear-cut Raman spectra of molecules in the gas phase were reported indepenpently by Wood and by Rasetti in early 1929. Wood studied the vibrational bands of HCl and NH_3 [9] and Rasetti those of N_2, O_2 and CO[10]. The former paper goes into great detail about the proper technique for gas-phase Raman spectroscopy, and much of it became standard practice in the pre-laser era.

Wood himself apparently never returned to a grating instrument for Raman work, but his successful production of blazed gratings for the visible region[11] in the late 1930's enabled others to make successful use of their higher speed and angular dispersion as compared with multiple-prism spectrographs. Early Raman studies with blazed gratings ruled by Wood were made by Rank and coworkers [12],[13] by Lord and Miller[14], and by Stamm[15]. Langer and Meggers also reported some spectra from unblazed gratings[16].

Wood published some thirty articles on the Raman effect in the decade 1928-38, all but three of them without a collaborator. However, the stimulus provided by his early publications played a large part in convincing U. S. physicists and chemists of the value of research in Raman spectroscopy.

It is impossible in a brief discussion to do justice to the many early workers in this field, but several centers of Raman research must be mentioned. At wood's own university, the Johns Hopkins, other professors in physics (A. H. Pfund, G. H. Dieke) and chemistry (D. H. Andrews) were active.

At the California Institute of Technology, physicists and chemists both made early contributions. In addition to Rasetti, whose work on gases at Caltech[10] has already been referred to, the physicists R, G. Dickinson and W. V. Houston carried out other gas–phase studies on ammonia [17], methane [17], carbon dioxide [18] and acetylene [18]. Significant contributions by chemists included many early papers by D. M. Yost and his students T. F. Anderson, F. Stitt and other [19], as well as the classical work of E. Bright Wilson, Jr. on the group-theoretical analysis of the vibrational modes of the benzene molecule[20].

When Wilson moved to Harvard in 1934, he established a group productive of research in Raman and infrared spectra that flourished until its interruption by World War II. His many students and coworkers included J. B. Howard, H. Gershinowitz. W. H. Avery, B. L. Crawford, Jr., J. W. Linnett, and F. Stitt [21]. Another collaborator of Wilson was the biological chemist J. T. Edsall of the Harvard Medical School[22], who had independently undertaken investigations into the Raman spectra of amines, amino acids, urea and other simple biologically important compounds[23]. This was the start of two decades of pioneering work by Edsall on the Raman spectroscopy of biomolecules. The importance of the research area thus opened up is attested by the large number of papers on this subject at the International conferences.

Other centers of Raman spectroscopy in the United States in the early 1930's were those of D. H. Rank at pennsylvania State College [24], J. Rud Nielsen at the University of Oklahoma [25], and G. Glockler at the University of Minnesota (later at the University of Iowa) [26].

World War II was a watershed in the history of the Raman effect in the United States. In the postwar period, new instrumental developments improved the scope and precision of Raman spectroscopy.

These improvements included the adoption of blazed gratings as dispersive elements, the use of photoelectric recording (pioneered in the United States by D. H. Rank [27], the development of intense, low-pressure mercury arcs with minimal background continuum, and the production in the mid 1950's by H. Cary of a commercial spectrometer incorporating all these elements, the "Cary 81".

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THE RAMAN EFFECT

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When a beam of light is passed through any transparent substance, a very small fraction of the same is scattered in all directions making the track of the beam inside the medium visible. This is a very well known phenomenon and in the case of colloids and emulsions, it is called Tyndall Scattering, while in the case of ordinary liquids, gases, crystals and glasses, it is known as Rayleigh scattering or molecular scattering. In both cases there is no change of wavelength or colour of the scattered beam from that of the incident beam. In the case of Rayleigh scattering, if white light is used there is a relative enhancement of the different colours already present in the incident beam. The blue colour of the sky itself is a simple result of scattering of sunlight by the molecules of the air, the efficiency being greater for light of shorter wavelengths (scattering intensity being proportionl to the λ^{-4} law). While working on molecular scattering of light in diverse media in the Indian Association for the Cultivation of Science in Calcutta, Professor C. V. Raman discovered an yet another scattering phenomenon, namely a change of wavelength in light scattering. The discovery was made on the 28th February 1928 and given publicity in the News papers the next day. Raman submitted a note[1] entitled "Change of Wavelength in Light Scattering" on March 8, 1928 which was published in *Nature*, London on April 21, 1928. The first detailed announcement of the discovery before a scientific audience with a description of the princ'pal features of the new effect was made by Raman under the title "A new Radiation" on March 16. 1928, while inaugurating the South Indian Science Association at Bangalore. The full text of the lecture under his authorship was published over night as a Special Number of the Indian Journal of Physics[2] of which Raman was the

Editor. Reprints of this article were posted immediately to all leading physicists and Scientific Institutions all over the world thus ensuring priority for Raman's discovery. The discovery was immediately acclaimed everywhere as Raman Effect. Raman was awarded the Nobel prize for Physics in 1930 and during the presentation, the Chairman of the Nobel Committee said:—"The Raman Effect has already yielded important results concerning the chemical constitution of substances; and it is to forsee that the extremely valuable tool that the Raman Effect has placed in our hands will, in the immediate future, bring with it deepening of our knowledge of the structure of of matter". In the same year while presenting the Hughes Medal of the Royal Society, Lord Rutherford, President of the Royal Society of London, said:–"Sir Venkata Raman is one of the leading authorities on optics, in particular on the phenomenon of scattering of light. In this connection about three years ago he discovered that the light's colour could be changed by scattering. This has been predicted theoretically some time before, but in spite of search, the change had not been found. "The Raman Effect" must rank among the best three or four discoveries in experimental physics of the last decade. It has proved, and will prove an instrument of great power in the study of theory of solid"[3].

Since the discovery, Raman effect has become one of the most useful techniques available for the study of molecular structures. The development of lasers nearly twenty seven years ago completely revolutionized the practice of Raman spectroscopy. Studies on Raman Effect have increased by leaps and bonnds with regard to range and coverage and versatility of its applications. No other discovery in science had such dramatic rejuvention and renaissance. Nearly on an average 200 papers are published on Raman Effect every month. In view of this widespread application, it is proposed in this article to explain in a simple way what Raman Effect is, the work which finally led to its discovery, its significance and applications.

During a voyage to Europe in 1921, Prof. Raman was impressed by the deep blue colour of the Mediterranean Sea and carried out some experiments with a nicol prism and came to the conclusion that the colour was mainly due to the molecular scattering of light by more or less dust free sea water. He returned to Calcutta and started a series of investigations on the scattering of light in diverse media. In 1922 he wrote a monograph entitled "Molecular Diffraction of Light" published by the Calcutta University Press in which he had clearly indicated that there might be experimental observations in light scattering which might require the use of Einstein's photon concept in place of the classical wave theory. This was confirmed six years later on 28 February 1928 by discovering a new effect. In 1923 Compton discovered an effect that bears his name. When monochromatic X–rays were scattered from a graphite block, two components were observed, one corresponding to the incident beam, the other shifted in frequency by an amount that depended on the scattering angle, but was independent of the initial wavelength and the scattering substance. Raman began a search for the optical analogue of Compton effect in the visible region. In 1923, K. R. Ramanathan, a distinguished student of Raman, while investigating the scattering of light in pure and dust free water and alcohols, reported a weak fluorecence in the green region when sunlight filtered through a violet glass filter passed through the liquids[4]. Neither Raman nor Ramanathan could find a satisfactory explanation for the "weak fluorescence". Later continuing the scattering experiments in a large number of pure and dust free organic liquids, K.S. Krishnan, another distinguished student of Raman, not only confirmed the existence of the weak fluorecsence, but also recorded the partially polarised nature of the weak flourescence, the intensity and extent of partial polarisation varying with liquid to liquid[5], showing thereby that the 'weak fluorescence' was different from ordinary fluorescence which would be unpolarised. Raman himself observed the phenomenon in optical glasses and in a crystal of ice[6].

The next important stage in the history of light scattering was the observation of S.Venkateswaran, a part time research scholar in Raman's laboratory. While working with pure dry glycerine, he found that when the incident sunlight was filtered through Corning Glass blue filter, the transversely scattered light was brilliant green in colour and strongly polarized.

This prompted Raman and Krishnan to take up an intensive study of the origin of the weak fluorescence. In the morning of 7th February, 1928 Krishnan observed the same effect in a large number of aromatic liquids with a more pronounced polarisation character. As K.S. Krishnan had noted in his diary, on the night of the same day Prof. Raman rushed to Krishnan's residence to tell the latter that their observations made that morning were related to the Kramers-Heisenberg dispersion process for which they have been looking for all these years. They christened the effect as "Modified Scattering". Two days later Raman and Krishnan detected the new radiation in vapours of ether and amylene. They soon realized that they were dealing with a new phenomenon of a fundamental nature and communicated their conclusions by cable to *Nature* on 16th February in a note entitled "A New Type of Secondary Radiation"[7]. Later they succeeded in detecting the new radiation and observing its partial polarisation in a large number of organic vapours also.

While continuing further studies on the subject Raman and Krishnan proceeded to examine the influence of the wavelength of the incident light on the new radiation in the afternoon of February 28th. By reducing the band width of the incident radiation with the use of a blue violet filter and a piece of uranium glass in the path of sunlight, they examined the light scattered by benzene kept in a flask through direct vision spectroscope and were surprised to find that the modified scattering was separated from the Rayleigh band by a dark space. This encouraged them to use the 4358 A radiation from a quartz mercury arc. Besides the usual mercury lines, the scattered spectrum exhibited new lines of different wavelengths, characteristic of the substance under study. After confirming that the effect was observed in a large number of liquids and in some gases and also in a block of ice, Raman made the first public announcement of this discovery to the Associated Press of India on February 29, 1928 and sent a communication to *Nature*[1] on 8th March under the title "A Change of Wavelength in Night Scattering". The story goes that this note to Nature sent by Raman announcing the discovery was rejected by a referee but published anyway by the Editor, Sir

Richard Gregory. The scattered spectra were photographed using a Hilger Baby Quartz spectrograph and mercury arc excitation. The first detailed announcement of the discovery before a scientific audience with a description of the principal features of the new effect was made by Raman under the title "A New Radiation" on March 16th while inaugurating the South Indian Science Association in Bangalore. The full text of the lecture with a photograph of the scattered spectrum of benzene was published as a Special Number of the Indian Journal of Physics[2] on 31st March. In this paper he stressed on the universality of the phenomenon and its usefulness for obtaining information about molecular structure. The important development was the realisation that the frequency shifts of the new lines appearing in the scattered spectrum from the exciting line were characteristic of the substance being examined. Immediately following the announcement of the discovery Raman and Krishnan[8] carried out systematic investigations on the new effect and established the following features:–

1. Every substance has its own characteristic Raman spectrum which serves to identify the same unequivocally.
2. The frequency shifts of the Raman lines are independent of the frequency of the exciting line
3. Raman lines are generally narrow in gases, liquids and crystals, while in amorphous substances, the lines are broad and diffuse. In the case of liquids, there is also a continuum (wing) adjacent to and on either side of the exciting line, the extent of continuum varying from liquid to liquid.
4. Raman lines have frequency shifts from the exciting line varying from about 4000 to a few wavenumbers (cm^{-1}).
5. The Raman lines often occur in pairs identically separated in frequency shifts on either side of the exciting line. On longer wavelength side they are termed as Stokes lines, while the ones appearing on the reverse side as anti-Stokes lines. The Stokes lines are generally more intense than the anti-Stokes lines.

6. The intensity of Raman scattering increases as the wavelength of the exciting line decreases in accordance with the λ^{-4} law, except in the neighbourhood of resonance absorption.

7. The frequency shifts observed in Raman scattering are the frequencies of oscillation of the chemically bonded atoms of the molecule, the latter being dependent on the geometry of the molecule and the forces of chemical affinity. They closely agreed in many cases with the frequencies of infra-red absorption bands of the same substances. The fundamental and most important aspect of Raman scattering is that it provided an easily accessible tool for the spectroscopic investigation of energy levels of systems not easily accessible by the usual infra-red absorption or emission techniques.

It is interesting to point out here that in 1927 the French group was working on the scattering of light in gases and Rocard had investigated the effect of an oscillating dipole on the scattering process; but he did not publish his results for want of experimental verification. After seeing Raman's publications[1] and[2] he published his calculations and he interpreted the frequency shifted scattered light as an optical modulation caused by the various vibrational frequencies of the oscillating molecules[7]. During the same period Landsberg and Mandelstamm were performing scattering experiments with a crystal of quartz in the Institute of Theoretical Physics in Moscow. While looking for change of wavelength that could be explained on the basis of Debye theory using mercury radiations as exciter, they reported frequency shifted lines in quartz and calcite in spectral regions different from those expected on Debye's theory. On May 6th, they submitted their results as a letter (Zuschrift) in Naturwissenschaften[10, 11] after the publication of Raman's notes in Nature of March 31[7] and April 21[1]. Their paper appeared in print after 16 other printed papers on the effect by various authors had appeared in recognised scientific periodicals.

In simplest terms Raman effect is an inelastic scattering process in which the interaction between the light quantum of energy hν and a molecule is considered as a collision satisfying the laws of conservation of energy. The incident photon loses part of its energy on collision with a molecule thus raising the latter to an excited state, the remaining part of the photon energy appears as a radiation of lower energy or lower frequency and appears in the Raman spectrum as a Stokes line. There are collisions in which the molecules which are already in excited states, give energy to the photon and come down to lower energy states giving rise to scattered photons of higher frequency. They appear as anti-Stokes lines.

The importance of Raman's discovery was immediately recognised by Pringsheim[12] and R. W. Wood[13] and their subsequent work confirmed Raman's findings. Pringsheim christened the new scattering phenomenon as Raman effect and the spectrum of the new lines as Raman spectrum. In a cable to Nature, Wood stated as follows:- "...Raman's brilliant and surprising discovery opens up a wholly new field of study of molecular structure. I have verified this discovery in every particular . It appears to be that this very beautiful discovery which resulted from Raman's long and patient study of phenomena of light scattering is one of the most convincing proofs of quantum theory of light which we have at present". R. W. Wood was the first to introduce the term "anti-Stokes" referring to the Raman lines on the higher frequency side. Wood published more than 30 papers on various aspects of Raman effect during the next ten years. It should be emphasised here that the modern theory of resonance Raman scattering in gases and the current experiments with the same gases studied by Wood at the beginning of this century point to an interpretation of resonance fluorescence as a special case (discrete resonance Raman scattering) of a more general Raman scattering process. Many other physicists in France, Canada, Italy and USA confirmed Raman's findings and extended the scope of investigations.

Immediately after the discovery of Compton effect in 1923, A. Smekal, an Austrian Physicist was working out theoretically the interaction of radiation with matter quantum mechanically and came to the conclusion that the energy of the incident radiation might be lowered by an amount equal to the energy difference between the normal and excited energy states of the system. He published his results as a note in 1923 [14]. The developments that followed the above publication have been summarized by Placzek in his book on Rayleigh–Streuung und Raman Effekt"[15]. "Encouraged by Smekal's note, Kramers and Heisenberg[16] showed how the origin of this modified scattered radiation can be understood classically, and after this they were able to derive their quantum mechanical scattering formula by combining the correspondence principle with the classical theory of the electromagnetic radiation. The importance of this investigation by far exceeds this field of problems: it was the origin of modern quantum mechanics". In 1927. Dirac[17] developed a quantum mechanical scattering theory from which he derived the formula for the intensity of scattered radiation. Thus the theory of Raman effect was firmly established one full year ahead of its experimental discovery, These publications were highly mathematical and no experimental physicist working on light scattering took any notice of them. It was only after Raman's independent discovery that the full implications of the dispersion theory came to be recognized [18]. Max Born[19] in a note entitled "Theory of Raman effect" stated that Raman's discovery had been predicted by quantum mechanics in all its entirety and could be thought of as a proof for the same.

In his Presidential Address to the Annual Meeting of the Indian Science Congress Association held at Madras in 1929, Prof. Raman made the following concluding remarks: "Associated with me during the last 8 years were a great many physicists in our laboratory. Among them, I would specially mention the names of Dr. K. R. Ramanathan, Dr. K. S. Krishnan and S. Venkateswaran by reason of their conspicuous originality in research and in view of the importance of their personal contributions to the development of the new effect under discussion. To them I owe a debt of gratitude".

The Indian Journal of Physics was started by Raman in 1927 and did not have much of a circulation in 1928, Raman had to publish his March 16th lecture on "A New Radiation" in this Journal in order to avoid any delay in publication. In order to get maximum publicity to his discovery, reprints of this important paper were posted to those working on light scattering in France, Germany, Russia, Canada and USA and to important Scientific Institutions all over the world, thus ensuring priority for his discovery. The history of the discovery of Raman effect teaches many lessons. Firstly, hardly any discovery appears immediately in its clear and final from. Facts are brought out step by step. Secondly, it is the calibre of the scientist that matters for scientific break–through and not the provision of costly equipment or building. Thirdly, sustained effort in a single field will ultimately lead to success and fame. Fourthly, great discoveries always appear incredibly simple, but only after some devoted person has made the discovery. Fifthly, quick publication of the results is a must to get priority over others working in the same field.

Although Dirac had given the quantum mechanical theory of scattering one year before the discovery, the numerical evaluation of the Raman intensity required the knowledge of all the eigen states of the scattering system. Even for the simplest of these molecules, the challenge remained unsolved for a long time. In this connection an important theoretical contribution made by G. Placzek in 1934 entitled "Rayleigh–Streuung und Raman-Effekt"[15] was very timely. Placzek developed the bond polarizability theory of Raman scattering and derived expressions for the intensity of Raman scattering under certain eonditions, in terms of the parameters related to the electronic ground state only. The main advantage of the polarizability theory was that group theoretical methods could be applied for deriving the selection rules for Raman effect from the symmetry character of the polarizability. Even after the last 50 years Placzek's theory is finding applications in the derivation of formulae for the hyper, stimulated, inverse and electronic Raman effect and other nonlinear phenomena which have come to prominence with the development of high power lasers and tunable dye lasers. Another important publication of a theoretical character which appeared in 1955 is the book entitled

"Molecular Vibrations" by Wilson, Decius and Cross[20]. This is extremely useful for chemists for normal coordinate analysis of vibrations of molecules and to calculate the molecular parameters and structure from the vibrational spectra.

The important parameters obtained from Raman spectroscopy are the frequency shifts, the degree of polarization, the intensity and the width and shape of the Raman lines. The frequency shifts are expressed in wavenumbers (cm^{-1}), and are obtained as the differences of the wavenumbers of the incident exciting line and the corresponding Raman lines. If these are multiplied by 3×10^{10} (velocity of light) one gets the actual frequencies of the Raman shifts. The degree of polarization is always expressed as the ratio of the intensities of the horizontal component to the vertical component of the Raman line.

The principal components used for recording the Raman spectrum of a substance are the following:-1) A source of monochromatic radiation, 2) a container with transparent windows and a suitable gadget for varying the temperature and pressure of the sample, 3) a dispersing instrument and 4) a detecting cum recording system. For the first 35 years, the 4358, 4046 and 2536A radiations of the mercury arc were used as sources. A spectrograph of moderate dispersion and photographic recording were mainly used. The Raman effect studies during this period were confined to the establishment of quantum mechanical principles and supplying information about the structure and other fundamental parameters of molecules and crystals than with practical applications except in chemical analysis and identification of compounds. The technique of excitation by 2536 A mercury resonance radiation together with mercury vapour filter in the path of the scattered beam first adopted by Rasetti and later developed and extensively used by the present author and his associates at Bangalore in the Forties and Fifties provided valuable information concerning the lattice dynamics of crystals.

Studies on Raman effect were mainly confined to vibrational, rotational and anisotropic (Raman wing) spectra of molecules in the gaseous or liquid states and to the internal and lattice spectra of mostly clear and transparent crystals. Studies on Raman spectroscopy have helped in understanding the nature of many chemical problems such as association, dissociation, polymerization, molecular interaction, nature of the chemical bond, hydrogen bonding, isomerism, molecular rotations, solvent effect, spectra structure correlation, change of state, phase transition, etc. Even some studies on electronic Raman scattering (ERS), Resonance Raman scattering (RRS) and Raman spectroscopy near phase transitions were carried out with some success.

The development of gas lasers in the early sixties completely ravolutionised Raman spectroscopy. The modern laser radiation is highly monochromatic, completely polarized, perfectly coherent, easily controllable, of exceptionally high specific intensity and negligible divergence. Since 1965, the most commonly used lasers for Raman excitation are the continuously operating He-Ne (6328A), Ar^+ ion (4880,5145 A) and He-Cd (4415 and 3250 A) gas lasers and the pulsed and the continuously operating forms of Ruby (6943A) and the Nd-YAG (1.06 micron) solid state lasers and since 1970 tunable dye lasers of continuously variable wavelength in the visible region. Due to the very small cross sectional area of a laser beam and the high power densities of light that can be made available at the focal point of the laser radiation as a consequence of its coherence, a new vista of micro-Raman spectroscopic analysis had begun enabling one to extend Raman effect studies to biological and biomedical samples available only in very small quantities or concentrations either by themselves or in solution.

The most startling developments during the laser era were the discoveries of new types of Raman excitations envisaged in the quantum theory of Smekal[18], but not realised in the prelaser era because of the limitations of the experimental techniques used. They are Raman scattering by polaritons, magnons, plasmons, plasmaritons, Landau levels, excitons, soft modes connected with phase transition, and nonlinear scattering processes such as stimulated, inverse, hyper, coherent anti-Stokes, and coherent Stokes Raman scattering, Raman induced Kerr effect, surface enhanced Raman scattering and resonance Raman scattering.

The development of more sensitive photomultiplier detection and electronic recording devices and computer interfaces for integrating Raman data from weakly scattering substances revolutionized the practice of Raman spectroscopy. With the progressive innovations in the techniques of excitation and detection using lasers of low and high power, accurate data on the frequency shifts, intensity, width, line shape and depolarization factor of the electronic, vibrational, rotational, lattice and internal Raman spectra of many compounds and crystals including those of coloured and opaque substances like metals have been collected. It became easy to record the spectra of solutions, single crystals, powders, films etc. maintained at any desired temperature and pressure.

I shall now explain the significance of some of the new types of excitations. Raman scattering by polaritons arises by light scattering by elementary excitations corresponding to mixed states of mechanical and electromagnetic energy. Hopfield[22] christened these coupled excitation states as "Polaritons" in 1958. Oriented spins in a magnetic material are coupled and interaction by a photon in such creates a spin wave which travels through all spins. Quantised states of spin waves are called magnons and they give rise to Raman scattering which was first predicted by Elliot and Loudon in 1963[23] and was first observed by Fleury and Porto in MnF_2 and FeF_2, in 1966[24]. Plasmons are quantised levels of electronic oscillations in a semiconductor. Under the action of a photon they give rise to Raman scattering by plasmons. This was discovered by Mooradian and Wright in 1966[25]. When a semiconductor is placed in a magnetic field the circular trajectories of the electrons are quantised in cyclotron orbits known as Landau levels. Raman scattering from such levels in indium antimonide was first discovered by Slusher, Patel and Fleury in 1967[26]. Near a struct-

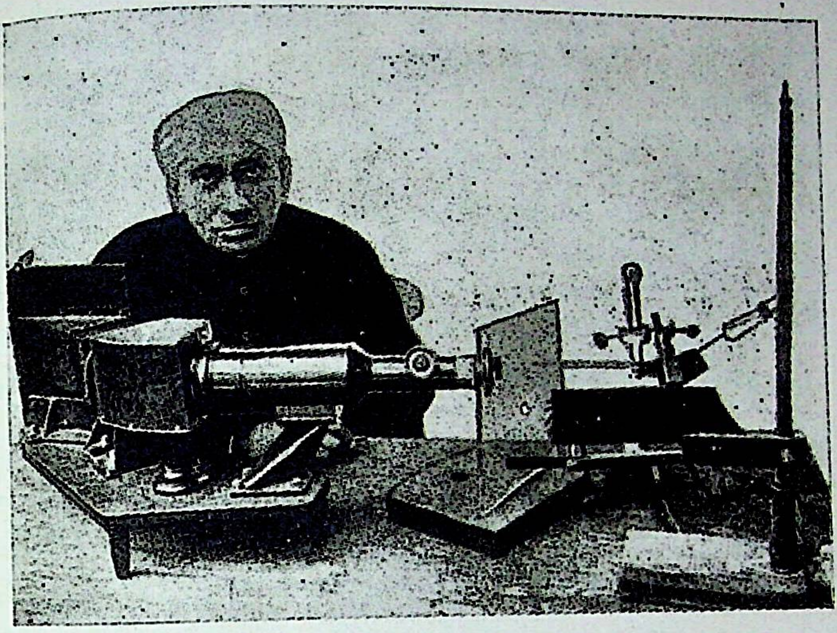

Fig. 1. Experimental arrangement used by C. V. Raman for discovering the Effect.

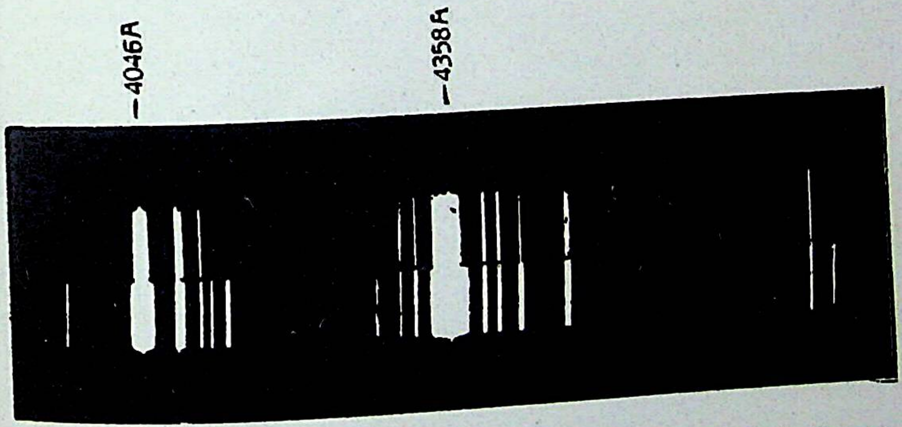

Fig. 2. Raman spectrum of Carbon tetrachloride taken by C. V. Raman and K. S. Krishnan.

ural phase transition in a solid the frequencies of one or more optical phonons decrease as the transition temperature is approached. They are called soft modes. The existence of such a mode was first demonstrated by Raman and Nedungadi in the Raman spectrum of quartz near the alpha-beta transformation in 1940[27]. Spin-flip Raman scattering arises from a transition between Landau levels with a change of quantum number by two. In this process under the action of a photon, the spin of the electron flips between two opposite directions and the Raman frequency is double the cyclotron frequency of the electron. This was first observed by Slusher, Patel and Fluery in 1967[26]. Nonlinear Raman scattering arises from the fact that the induced dipole moment is not only linearly dependent on the applied electric field of the light wave but on higher powers of the field. This usually appears when high power radiation from a Q-switched laser is used for excitation of Raman spectra. Hyper Raman scattering occurs when nonlinear inelastic scattering takes place with higher harmonics of the incident radiation as exciter[28]. In the stimulated Raman scattering[29] the scattering process involves four photons, two with the frequency of the incident radiation and one Stokes and anti-Stokes radiations. High power lasers have to be used. Unlike the ordinary Raman scattering only very few Raman lines and their harmonics are excited. When a medium is irradiated simultaneously by an intense monochromatic light and a continuum, sharp absorption lines are observed on the anti-Stokes side corresponding to Raman transitions, and this is termed as Inverse Raman effect[30]. Electronic Raman scattering[31] takes place when the energy is conserved by the quantum jump of an electron from one electronic state to another. This is mainly observed in gases and solids. When the exciting frequency is close to or coincides with the absorption frequency the scattering intensity is very much enhanced and the process is called resonance Raman scattering[32]. A nonlinear Raman process generated by the third order nonlinear susceptibility of the material by the simultaneous excitation with two lasers of frequencies ν_1 and ν_2 such that $\nu_1 - \nu_2$ coincides with a quantized state of the medium, is now termed as the coherent anti-Stokes Raman scattering or CARS[33]. In order to record the full Raman spectrum by CARS process, the frequency ν_1 of the pump radiation is kept constant, while the frequency ν_2 of the second laser radiation is varied over a wide range to cover the entire Raman spectrum. CARS is superior to normal Raman scattering because of its very much larger scattered intensities restricted to a very small solid angle and the signal is coherent. In the above four photon process if the frequency of ν_2 is greater than that of ν_1 one observes coherent Stokes Raman scattering[34]. Another scattering phenomenon recently discovered is the surface enhanced Raman scattering by Fleischman and others[35]. The Raman scattering cross-section for pyridine adsorbed on a silver surface was found to be six orders of magnitude higher than that of pyridine in bulk. This is the case with other molecules also adsorbed not only on silver surfaces, but also on other metal surfaces. Enhancement depends very much on the type of metal, the nature of its surface, whether it is a film or colloidal particle and also on the nature of adsorption and the molecule involved. Continued technological innovations and the development of more powerful visible and ultraviolet lasers, tunable dye lasers, time resolved and space resolved Raman spectrometers, picosecond pulsed Raman spectroscopy, multichannel analysers and Raman microprobes (Molecular Optics Laser Examiner, MOLE) have led to a second renaissance in the history of Raman effect in the seventies.

Raman spectroscopy has now found varied applications not only in Physics and Chemistry but also in Biology, Medicine, Engineering and technology. Some of the recent applications include flame and combustion diagnostics, temperature and density measurement of gases, chemical kinetic studies, air and water pollution measurements, environmental analysis, medical diagnostics, drug and enzyme reactions, insitu mineral analysis, mechanisms of phase transitions in solids, semiconductor morphology, production of tunable high intensity infra-red sources for communication, conformation of biological molecules, structure analysis of metallic surfaces, mechanism of human vision and corrosion studies. Raman spectroscopy is extensively used as an analytical tool in many chemical and pharmaceutical industries and for remote sensing operations (LIDAR).

In recent years the main thrust in instrumentation has been development of very powerful nanosecond or picosecond pulsed lasers for time resolved Raman spectroscopy[36] which is applied to study molecular structure and composition of short lived transients in photolysis and other chemical and physical reactions. Ultraviolet lasers have also been developed in the 184 to 260 nm region by applying the principle of repeated stimulated anti-Stokes Raman scattering in hydrogen under pressure and thus shifting the harmonics of a Q-switched Nd–YAG laser. This is in great demand for time resolved resonance Raman scattering. The development of laser Raman scattering microprobe has been perfected and are now available commercially for routine microanalysis. In this instrument a conventional microscope was coupled to a spectrometer equipped with a high sensitivity television type detector. The laser beam is focussed on a very small area of the order of a square micron or less in size on the specimen and the backward Raman scattering is analysed with a multichannel analyser. The entire specimen is scanned by moving it in different directions. The spacial resolution achieved is of the order 1 micrometer.

A Fourier transform Raman spectrometer has been developed for high resolution Raman spectroscopy of gases. The application of time resolved spectroscopy has led to a more accurate description of the mechanisms involved in a number of photochemical, photophysical and photobiological processes. Transients up to 0.1 picosecond time scale have been studied. Because of the selectivity of resonance enhancement, structural information can be obtained from complex bio–molecules, such as hemeproteins and visual chromophores.

Raman spectroscopy has been widely used as a versatile tool for understanding the nature of phase transitions in many new ferroelectrics and ferroelastics. Hyper Raman spectroscopy has been successfully used recently to study the soft mode behaviour of $SrTiO_3$ near the transition temperature, since this mode is inactive in normal Raman scattering.

Surface enhanced Raman spectroscopy[37] is finding increasing applications in determining surface microstructure of industrial materials and also to study the vibrational structure of many chemical entities and biomolecules available only in small quantities because of the increased scattering cross section under SERS conditions. The Raman microprobe has provided an invaluable tool in recent years for the industrial world for true microanalysis of products and contaminants especially in microelectronic and semiconductor fields. It is now used as an important tool in quality control of manufacturing processes in integrated circuits, study of corrosion of metal surfaces, etc. MOLE supplies information on a microscopic scale about chemical composition, crystal structure, intermolecular interaction, lattice and molecular orientation of mineral specimens. It is capable of being used for in-situ examination. Resonance Raman spectroscopy has been used for the study of the behaviour of many heme–proteins under the action of drugs, study of enzyme-substrate intermediates in the millisecond time scale.

Coherent anti–Stokes Raman spectroscopy is very widely used for determining the molecular vibrational and rotational constants very accurately. It is applied in remote detecting systems and in the measurements of temperature and species concentration in combustion engines, jet engines, industrial furnaces and their exhausts[38]. It is also used for air pollution measurements in environmental studies. CARS technique is also used for the study of many transient species formed under chemical and physical processes.

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APPENDIX

Glossary of Raman Excitations and their abbreviations :

1. Spontaneous or First Order Raman Scattering : (SpRS or FORS)

This is the normal Raman Effect in which light of frequency incident on matter produces, scattered light of weak intensity with same frequency (Rayleigh scattering) and additional weak spectral lines (Raman scattering) with frequencies ν_R '*s*, where ν_R is an eigen frequency of the scattering system. It is linear because of the linear relationship between the induced dipole moment and incident electric field $P = \propto E$.

2. Combination Scattering

Russian synonym for Raman Scattering.

3. **Nonlinear Raman Effect : (NLRE)**

Induced moment is proportional to higher order terms of the incident electric field.

$$P = \alpha E + 1/2\ \beta E^2 + 1/6\ \gamma E^3 + \ldots\ldots$$

4. **Vibrational Raman Effect/Scattering : (VRE/VRS)**

This process takes place between vibrational quantum levels of the system and frequency shift of the Raman line directly gives the vibrational frequency of the molecule.

5. **Rotational Raman Effect/Scattering (RotRE/RotRS)**

6. **Phonon Raman Scattering :**

This process is due to scattering by waves propagating in a crystal. These waves are quantised and are termed phonons or normal modes of vibration of the crystal. In FORS only those phonons with wavevector

$|\vec{k}| = 0$ are active.

7. **Raman Wing (Wing accompanying the Rayleigh line)**

In liquids there is a hindrance to molecular rotation. It therefore appears as a continuous wing to the Rayleigh line starting with maximum intensity either or adjacent to the unmodified line and extending somewhat unsymmetrically on either side with continuously decreasing intensity. The intensity and width of the wing are clearly related to the anisotropy of the molecules of the liquid.

8. **Electronic Raman Effect/Scattering (ERE/ERS)**

In this scattering process the transition takes place between two electronic levels

9. **Second Order Raman Scattering (SORS)**

The scattering process in which the polarizability is modulated by a frequency correspondig to the vibrational overtones or combinations in liquids or gases or two phonon frequencies in the crystal.

Raman lines appearing in the SORS are generally weak and the frequency shifts correspond to octaves and combinations of the fundamental frequencies.

11. Raman Scattering by Polaritons (PORS)

Polaritons are elementary excitations corresponding to mixed states of mechanical and electromagnetic energy in polar crystals. The frequency shifts of Raman scattering by polaritons vary with scattering angle, being of zero value along the forward scattering.

12. Raman Scattering by Magnons (MagRS)

Magnons are quantised states of spin waves in magnetic crystals. Oriented spins are coupled and disturbance by a photon in a crystal creates a spin wave which travels through all spins. The Raman scattering from magnons takes place if the material is kept in a magnetic field below the Neel temperature. FORS and SORS from magnons have been observed.

13. Plasmon Raman Scattering (PamRS)

This is light scattering by quantised plasma oscillations in semiconducting material.

14. Plasmariton Raman Scattering (PmrRS)

Light scattering by coupled photon-phonon-plasmon states (Polariton-plasmon).

15. Raman Scattering by Landau Levels (LLRS)

Light scattering by quantised cyclotron orbits inside a crystal. If a magnetic field is applied to a conductor or semiconductor, the translations of free electrons are superimposed with rotations at cyclotron frequencies. these quantised states are called Landau levels. InSb exhibits this type of scattering.

16. Raman Scattering by Excitons (EXRS)

Light scattering by quantized states in electron systems (semi-conductor and insulators) which are connected with the formation of bound electron-hole pair. These excitons propagate as waves through the crystal and can be excited by photons giving rise to Raman scattering.

17. Raman Scattering by Soft Mode (SMRS)

This scattering is due to an unstable or soft transverse optical phonon whose frequency decreases substantially as the transition temperature of a structural phase transition is approached.

18. Spin-Flip Raman Scattering (SFRS)

In this process under the action of a photon, the spin of the electronic state flips between two opposite directions resulting in Raman scattering and the shift is twice the cyclotron frequency of electrons.

19. Spin-Flip Raman Laser (SFRL) or Magneto Raman Laser (MRL)

Stimulated spin flip Raman transitions lead to coherent, tunable Raman scattering and a source of laser type radiation in the far infrared. Tuning is achieved by a change of the magnetic field.

20. Raman Optical Activity (ROA)

Small differences in the intensity of Raman scattered light from right and left circularly polarised light.

21. Circular Intensity Differential (CID)

A relevant quantity in measurements of ROA is the quantity CID which is given by

$$\Delta=\frac{I_R - I_L}{I_R + I_L}$$

where I_R and I_L are the scattered intensities from right and left circularly polarised incident light.

22. Stimulated Raman Effect/Scattering (SRE/SRS)

This is a nonlinear Raman scattering process involving four photons as given by the wave vector relation

$$2\vec{k}_i = \vec{k}_s + \vec{k}_{as}$$

(where i : incident, s : Stokes, and as : Anti–Stokes). This is excited by laser light with high power. In contrast to SpRS, only very few lines and their harmonics are generated. SRS radiation is coherent and can be used as a laser radiation.

23. Hyper Raman Effect/Scattering (HRE/HRS)

Nonlinear scattering process where, due to the high electric field of the exciting radiation with frequency ν_1, HRS takes place in the vicinity of the frequency $2\nu_1$ as the exciting line with frequency shifts corresponding to vibrational, rotational or phonon frequencies. This is an extremely weak scattering process. Even those vibrations which are forbidden to appear in FORS, appear in HRS.

24. Inverse Raman Effect/Scattering (IRE/IRS).

This appears as sharp absorption lines on the anti-Stokes side when a medium is illuminated simultaneously by intense monochromatic light and by a continuum. Vibrational quanta are absorbed from the continuum, which leads to the absorption spectrum.

25. Discrete Resonance Raman Scattering (DRRS),

This is a special case of RRS when the exciting frequeney ν_1 is close to and coincides with an absorption transition between discrete levels (e.g. rotational-vibrational levels in a molecule of the gas phase).

26. Raman Gain

This process is generated via the third order susceptibility, using two intense laser beams. The intensity of one of the laser beams (probe) is enhanced by energy from the other (pump). This technique offers ultrahigh resolution when two continuous single frequency lasers are applied. The process is also known as Continuous Wave Stimulated Raman Gain Spectroscopy (CWSRGS).

27. Coherent Anti-Stokes Raman Scattering (CARS)

A nonlinear Raman process generated via the third order nonlinear susceptibility of the sample by simultaneous excitation with two laser radiations of frequencies ν_1, and ν_2. Coherent radiation is produced at frequency $\nu_3 = 2\nu_1 - \nu_2$ whenever $\nu_1 - \nu_2$ coincides with a Raman frequency ν_R of the medium. ν_3 corresponds to the anti–Stokes radiation with respect to ν_1. CARS is very intense, directional and coherent.

28. Coherent Stokes Raman Scattering (CSRS)

In the process described above if $\nu_2 - \nu_1 = \nu_R$, one observes coherent scattering at ($\nu_3 = 2\nu_1 - \nu_2 = \nu_1 - \nu_R$) as Stokes radiation.

29. Higher Order Raman Spectral Excitation Studies (HORSES)

This is regarded as a higher order mixing process, e. g., six wave or second order four wave mixing.

30. Raman Induced Kerr Effect Spectroscopy (RIKES)

A laser beam is made to induce a Kerr effect only at Raman-shifted frequencies. When a medium is illuminated simultaneously with a circularly polarised pump beam of frequency ν_1 from a high power laser and a weak linearly polarised probe beam of frequency ν_2, the nonlinear interaction gives rise to a new beam of frequency ν_2 which is perpendiculary polarised with respect to the original probe beam. The new beam exhibits resonance when $\nu_1 - \nu_2$ is near the frequency ν_R of Raman active vibration of the medium. This process is called RIKES. This is generally observed in some organic liquids.

31. Time Resolved Raman Spectroscopy (TRRS)

Using picosecond pulses, the resultant Raman spectrum is recorded instantaneously. This gives temporal resolution in nanosecond or picosecond range.

32. Time Resolved Resonance Raman Spectroscopy (TRRRR/TR^{3}S)

This is TRRS with resonance scattering.

33. Hight Resolution Rotation Spectra (HRotRS).

Rotational Raman spectra recorded under high resolution.

34. Surface Enhanced Raman Spectroscopy (SERS)

Raman scattering appearing with enhanced intensity from molecules adsorbed on metal surfaces.

SIR C. V. RAMAN

P. R. PISHAROTY
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1. Introduction

Sir Chandrasekhara Venkata Raman, Kt. M.A., D. Sc., F. R.S., Noble Laureate, while founding a Research Institute for Physics, in 1948, wrote :

> "It is my earnest desire to bring into existence a centre for Scientific Research worthy of our ancient country, where the keenest of intellect of our land can probe into the mysteries of the Universe and by so doing help us to appreciate the transcendent Power that guides its activities......"*

Pandit Jawaharlal Nehru in introducing India's Scientific policy Resolution to the Indian Parliament in 1957. wrote:

> "It is an inherent obligation of a great country like India, with its tradition of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science "

Thanks to the Science Policy Resolution, the Govt. of India has been encouraging science in this country through the opening of several Scientific Laboratories, the provision of large funds for science education and scientific research, by offering good conditions of service to scientists, by according them an honoured position, etc.

However, the spirit behind the above statements made by Raman and Nehru has not yet penetrated into the minds and working habits of a large number of scientific workers of this country. We hope that this SPECIAL ISSUE OF PRAJNA brought out as a part of the centennial celebrations of Raman's birth, would help in rectifying this flaw.

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*A facsimilie reproduction of these words in Raman's own handwritiug is given as Appendix-1.

In this article I propose to convey to the readers the scintillating personality of Raman, his great selfconfidence, his untiring devotion to the pursuit of science and the spirit of science he radiated. His *thinking and working habits* when adopted by even lesser men can lead our country to a high place in the scientific world to which we are entitled to as inheritors of a glorious civilisation.

Sir C. V. Raman's thinking and working habits he followed for almost eight decades can be summarised in just three words :

AMBITION, COURAGE, ENDEAVOUR

2. Raman's Spirit

Professor C. V. Raman has been a great *acharya*. He created new knowledge, imparted knowledge to others and nurtured young minds so that they could grow up, create new knowledge as well as spread a scientific culture. To Gandhiji, *Truth was God.* To Raman scientific pursuit was *a devotion to that Transcendental Power*. During a science seminar in which Raman was present, a distinguished scientist was referred to as one who could say the *last word* on a particular subject. Raman jumped up and said that he would prefer to say the *first word* on a subject. And that is exactly what he did in several several scientific fields : optics, x–rays, ultrasonics, human vision, etc.

Raman's view regarding the nurturing of young minds by scientists of the elder group, the main job of a University, is best summarised in his own words :

"If there is one fact more than any thing which stands out in the history of science, it is the remarkable extent to which great discoveries and youthful genius stand associated together. Scores of instances can be quoted in support of this proposition. Indeed, if one were to attempt to write a treatise on any branch of science in which all discoveries made by youthful workers were left out, there would be very little to write about. The fact of the matter appears to be that, other things being the same, the principal requisite for success in scientific research is not the maturity of knowledge associated with experience and age, but the freshness of outlook which is the natural attribute of youth. The conservatism which develops with increasing age, is thus revealed as a factor which militates against the great achievement in science. The great ideas seem to come mostly to youthful minds. Since however, much time is required to work out a new idea properly and fully, age and experience are not altogether useless in science. Upto a certain point, conservatism bred by age may even be useful as a brake on the wilder flights of youthful imagination. Further, even the elderly may, if they choose, retain and cherish a *youthful spirit* and outlook. So long, therefore, as they do not allow the conservatism of age to function as a suppressor of youthful genius, the elderly may continue to find themselves useful as guides and inspirers of research. On this view, indeed, the principal function of the older generation of scientific men is to *discover talent* and genius in the younger generation and to provide ample opportunities for its free expression and expansion."

That is perhaps *Raman's advice to the Professors*. His *advice to students* who aspire for scientific achievements is given below.

"Speaking as a teacher of twenty-four years experience, I can assert, withont fear of contradiction that the quality of the Indian mind is equal to the quality of any Teutonic, Nordic, or Anglo-Saxon mind. What we lack is perhaps courage, what we lack is perhaps driving force which takes one anywhere. We have, I think developed an inferiority complex. I think what is needed in India today is the destruction of that defeatist spirit. We need a *spirit of victory*, a *spirit* that will carry us on to our rightful place under the Sun, a *spirit* which will recognise that we, as inheritors of a proud civilisation are entitled to a rightful place on this planet. If that indomitable *spirit* were to arise, nothing can hold us from achieving our rightful destiny", May this special issue of PRAJNA instil that *spirit* in all its readers, particularly in the student readers who are to be the leaders of tomorrow.

3. Biography of Raman.

Born on November 7, 1888 at Tiruvanaikkaval, a small village about 5 kilometres south of Tiruchirapalli in South India, precocious Raman had a brilliant academic career. He stood first class first in the Matriculation examination of the University of Madras, when he had just completed eleven years of age. It is said that while he was in the middle school he built all by himself an electric dynamo starting from scratch.

In 1902, he passed his F. A. examination (10+2) from the A. V. N. College at Vishakhapatnam, where his father Shri Chandrasekhara Iyer was a Lecturer. Raman took a first class and secured a high rank and thereby won a scholarship for higher studies.

In January 1903 he moved to Madras and joined the Presidency College for the University course leading to a Bachelor's degree, with Physics as his main subject. In addition to his flair for science, Raman had an unusual appreciation of English Literature and a command of the English language associated with it Even in those days he had a fascination for the blue of the sea and its glittering which he could watch from his English Lecture Hall. Raman passed his B. A. Degree examination in December 1904, winning the first place and gold medals in English and Physics.

Being of a frail physique, the Civil Surgeon, Madras, disqualified him medically from proceeding to England for higher studies. So, early in 1904, he joined for the M. A. degree course in Physics at Madras itself. In an article written many years later for the centenary of the College, he wrote.

"Professor Jones believed in letting those (students) who were capable of looking after themselves to do so, with the result that during the four years I was at College, I enjoyed a measure of academic freedom, which seems almost incredible. To mention only one detail, during the whole of my two years' work for the M. A. degree, I remember attending only one lecture, and that was on the Fabry-Perot (spectrometer) by Professor Jones himself". That freedom given to Raman paid rich dividends. He wrote two research papers, while a student, and without any guidance from his professors. He had the first one published in the *Philosophical Magazine* (London), November 1906, and the other in *Nature*, an early issue of 1907. Raman passed his M. A. examination at the age of 18, in January 1907, with a First Class and topping the list of successful candidates.

In February 1907, Raman appeared for a competitive examination at Calcutta, held for selecting Civil servants for the Finance Department. He again topped the list of successful candidates. While still awaiting his posting Raman found a bride for himself–Loka Sundari Ammal. The story has it that on the first occasion he met her, she was playing on the Veena a kirtan *Rama ni samana evaru ?* (Rama, is any one your equal).

In June 1907, the young couple moved to Calcutta, where Mr. C. V. Raman joined as an Assistant Accountant General. Within a few days, he noticed a sign board: "*The Indian Association for the Cultivation of Science*", located at 210, Bow Bazaar Street. It was a privately endowed scientific Institution, founded in 1876 by Dr. Mahendra Lal Sarkar, who was no more. Shri Amrit Lat Sarkar, the son of the founder, was the secretary of the Association. Very soon Raman secured for himself facilities to work at the Association building. It was through his work here, that he later received the Nobel Prize for Physics in 1930.

For a brief two-year period, 1909 and 1910, he was posted away from Calcutta at Rangoon and Nagpur. There also he did a certain amount of scientific work using apparatus rigged up at his residence. He returned to Calcutta in 1911 on promotion, and continued his scientific work at the Association premises, on holidays, and outside office hours on working days.

In June 1917, Mr. C. V. Raman, joined the Calcutta University as Palit Professor of Physics, on an invitation by the then Vice–Chancellor, Sir Asutosh Mookerjee. In 1919, Dr. Amrit Lal Sarkar passed away, and Professor Raman was elected as the Honorary Secretary of the Association. He continued to hold these two positions, with great distinction till he left Calcutta for Bangalore in 1933. It was indeed most fortunate for the Calcutta School of Physics that both the Physical Laboratories of the University College of Science, and of the Association came almost simultaneously under the supreme leadership of the same dynamic personality endowed with a great scientific ambition, namely Professor C. V. Raman.

In April 1933, Professor Sir C.V. Raman (he was knighted by the Emperor of India in 1929), F.R.S., Nobel Laureate, left Calcutta to take up the Directorhsip of the Indian Institute of Science. Bangalore. There he created a new Department of Physics, which he guided and directed. This Department began functioning by the middle of 1933 with about a dozen young students. However, serious difficulties between Raman and the management arose, and the former was obliged to relinquish the post of Director, and accept continuing as Professor of Physics. This he did till 1949, when was superannuated after attaining the age of 60, in November 1948.

Early in 1949, he moved over to a building which he had constructed on the land graciously gifted by the Maharaja of Mysore on behalf of the present Govt. of Karnataka. He established a Research Institute there. Now it is known as the Raman Research Institute. In the initial stages, the funds required for the building and the equipment were partly by donations and partly his own. This place of work again became a centre of Research, to which he recruited a few brilliant Research Assistants and Research Scholars.

After a brief illness, Raman breathed his last in the early hours of 21 November 1970, a few days after he completed 82 years of age, full of scientific achievements and honours–national and international.

Thus passed away Sir Chandrasekhara Venkata Raman, the legendary figure of science in India, into the pages of history.

The Awards and Honours he received are listed in appendix-2. Bibliography of his publications forms appendix-3.

4. Raman's work habits

Apart from being gifted with a keen intellect, Raman had developed a capacity for sustained hard work. The driving force was an ambition to achieve something great. Often he had stated that success can come only through courageous devotion to the task ahead, and that there was "nothing worth in this world that can come without the sweat of our brow".

As mentioned earlier, soon after his posting as Assistant Accountant General at Calcutta in June 1907, he secured facilities for work at the Indian Association for Cultivation of Science (IACS). His work routine thereafter became extremely busy : 5. 30 AM arrives at the IACS, returns home at 9.45 AM, has a quick meal and goes to office ; after 5.00 PM he goes to IACS, straight, and comes home around 10.00 PM, Sundays were spent at the Association. Raman continued to follow practically the same routine, almost till the end of his life. He was a real *karma yogi*. Raman was capable of tremendous concentration on intellectual work. While at work he would just nod to a visitor or a student, politely request him to take a seat, and then not lift his head from his work-table for another two hours or more. Of course, he would profusely apologise to the visitor and quickly dispose him off by answering his demands to the visitor's satisfaction.

Professor Raman later selected a residence just behind the Laboratories of the Association, 210, Bow Bazaar street. When he became the Secretary of the Association in 1919, he provided a back door entrance to the Laboratories from his residence. By this he would enter the Laboratory at any time day or night. Often he used to work far into the night and when exhausted, sleep on one of the tables, to be woken up the next morning by Ashu Babu, the Assistant Secretary who lived on the premises. In later life also, his residence was close to his Laboratories, so that no time need be wasted in transit.

5. Anecdotes.

We give below a few anecdotes which bring out the *Spirit* of Raman.

5.1 While at Bangalore, a Physics Lecturer (Mr. X) at the Central College, greeted him one early morning and congratulated Professor Raman on being mentioned in the latest issue of *Nature* by a distinguished foreign scientist. Professor Raman got upset and asked Mr. X to get out of his presence. A few minutes later while I was passing that way, Professor Raman called me in. He was in a very agitated mood. He recapitulated what had happened just before, and said; "I never thought that political subjection breeded intellectual slavery." We are politically free for the last forty years. However, intellectual slavery still exists in many minds. Even good scientists of our country, feel very much elated when their work receives a mention by an American or British scientist.

5.2 Again at Bangalore, while I was working on a problem on X-rays, Professor Raman noticed on one morning that I was sitting in front of the X-ray tube in a *depressed mood*. On being questioned about the reason, I told him that the same problem was being tackled by a senior scientist at Cambridge with a 5 kilowatt X-ray tube, while I was struggling with a one kilowatt tube. Quick came the remark: "Oh simple ; Put a 10 kilo-watt brain on it." Obviously, that was how he worked in India and possibly that is how Indian scientists will have to work in India for several years to come.

5.3 On one evening Professor Raman saw me moving about in a dhoti and shirt. He called me and said : "Do you know the secret of health ? Keep yourself warmer than necessary," 5.4 In 1924, Professor Raman was elected a Fellow of the Royal Society of London. The University of Calcutta threw a dinner to felicitate him on that recognition of his scientific work. The Vice Chancellor Sir Asutosh Mookerjee was present. It seems that he asked Professor Raman, rather jocularly, "What next ?", and that the reply was brief but serious; "The Nobel Prize." Many would say that it was an evidence of his boastful nature. But it should be interpreted as his ambition and on a realistic estimate of his own powers. On 10 December 1930, he received the Nobel Prize for Physics–for the discovery of the optical phenomenon now known as the Raman Effect.

6. Scientific work at Calcutta (1907–1933).

During an active period of 65 years, commencing at an early age of 18, nearly 400 original scientific papers were published by Raman alone or in collaboration with others. (See Appendix-3).

Two of them were published while he was a student. Twenty two of them were published, while he was serving as a full-time officer of the Finance Department, based on work done outside office hours (1907-1917).

Commencing 1917. many young men, mostly aspirants for a Doctorate degree, gathered around him both at the University College of Science as well as at the Indian Association for the Cultivation of Science (IACS). The latter in particular was the scene of intense activity. Many of the Research Scholars used to stay inside and around the premises of the IACS, so as to be in a position to avail themselves of the meagre facilities as and when they were released by other workers. Several devoted scientists came from all over India to work under Professor Raman's stimulating guidance. They were gifted collaborators. That enabled Professor Raman to push forward steadily with his investigations. At that time work was carried in areas such as: Vibrations and Sound: Theory of Musical Instruments; Optical Studies on Diffraction; Colours and Interference; Colloids: Molecular Scattering of Light; X–Rays; Magnetism and Magneto–Optics and so on.

Raman had started work in acoustics even while in Government service, by interesting himself with the physical theory of musical instruments, particularly of the violin family (his father and his wife were good players on the violin, so also his elder brother Sri Subramanya Iyer, the father of the distinguished Astrophysicist and Nobel Laureate Prof S. Chandrasekhar). This involved a study of the vibrations of strings in great detail. He made fundamental contributions to the motion of the *bowed point* and the effect of the *bridge* in coupling the motion of the string to the resonating body of the violin. Later, he worked on the Indian musical drums–the *mridangam and the tabla.* He made the remarkable observation that these drums possess harmonic overtones because the drum heads are loaded by sticking at appropriate places on the membrane, varying amounts of soft material. In Bulletin 15 of the IACS, Professor Raman published a fully worked out physical theory of musical instruments of the violin family and an experimental verification of the results thereof. Some years later, he wrote a comprehensive long article on the Physics of Musical Instruments. which was published in the *Handbuch der Physik,* eighth volume, 1927.

Professor Raman's best known work during his Calcutta days was in the field of optics in general, and Molecular scattering of light, in particular. Commencing with a critical examination of optical effects like the coronas, glories and haloes, studying the diffraction of light by emulsions, and by colloidal solutions, passing through similar studies on the scattering of light by molecules in all the three transparent states of matter, his work in those years culminated in the discovery of Raman Effect on February 28, 1928.

7. Some details about the Raman Effect :

In 1921, while travelling on board a steamship to England, Professor Raman was fascinated by the deep blue opalescence of the Mediterranian sea. Several years earlier Lord Rayleigh had stated that the blue of the sea was just a reflection of the blue of the sky, which he had explained as due to the scattering of sun-light by the molecules of air. Raman had his own doubts. He felt that the colour of the sea should be largely attributed to the scattering of light by the molecules of the sea-water. During the return voyage he confirmed it by a simple experiment. Reflected light from the sea at the Brewster angle must be completely plane polarised and extinguishable by a proper orientation of a Nicol prism. Raman's experiment showed that the blue of the sea was even a deeper blue as the reflected light was extinguished by the Nicol prism.

These observations became the starting point for the detailed investigations on the scattering of light by gases and transparent solids, for the next several years. When a beam of white sunlight is condensed by means of a lens into the centre of a large glass bulb containing a dust free transparent liquid like water or benzene, an observer who shields himself from the direct rays of the source and views the track in the liquid, in a transverse direction, will see a magnificient blue scattering. Insertion of a filter in the path of the incident beam and of a complimentary filter between the observer and the light scattering track, should render the track invisible. However, the track continued to be visible in the case of several liquids, gases and transparent solids. Several of the collaborators who carried out the experiment explained the phenomenon as due to flourescence produced by traces of some impurity.

Professor Raman had his own doubts. He felt that it was not a phenomenon due to impurities and fluorescence. He had a feeling that the molecules of the pure substance were themselves responsible for the observed phenomenon. He became aware of the remarkable brilliant monochromatic illuminator which could be obtained by the aid of commercially available mercury arcs sealed in quartz tubes. Towards the end of February 1928, he used such lamps (instead of sunlight) in the field of light scattering, with immediate results. Experience in working with sunlight had indicated the technique necessary for the observation of extremely weak pehnomena, viz,, the rigorous exclusion of stray light and the conditioning of the observer's vision by a prolonged stay in darkness. On setting up the apparatus and making these preparations Professor Raman found that the light of the mercury are diffused by various transparent materials, when examined through a *direct vision spectroscope* showed the presence, besides the lines of mercury, also of other lines, the positions of which varied with the substances under study. While a large part of the light scattered possesses the same frequency as that of the incident radiation, a small fraction thereof consists of light which has undergone a change (or changes) of frequency, the extent of change (or changes) being identical with the frequency (or frequencies) of oscillation of the components of the molecules of the scattering substance. This is the Raman Effect.

Studies on the Raman Effect in liquids, gases, and transparent solids were vigorously pursued at Calcutta and later at Bangalore; through the use of spectrograph and photographic plates, the additional lines were recorded clearly. However, with the light sources available then, long exposures, some times as long as 48 hours, were necessary to record the very feeble Raman lines photographically. So after a steep rise in the number of papers in the years following the discovery, a gradual decline set in the number of publications on the subject. But, with the development and use of intense LASER beams as a source of illumination, a new phase of renewed activity occurred in the application of Raman Effect in industrial and pharmaceutical chemistry.

8. Raman's Scientific work at Bangalore

Prof. Raman shifted his activities to Bangalore in April 1933. One of the areas in which he made a significant contribution during the years of his work here is on the diffraction light by high frequency sound (ultrasonic) waves. When a beam of monochromatic light traverses a liquid cell in which ultrasonic waves are maintained with the help of a piezo–electric oscillator, interesting diffraction effects are noticed and several papers relating to these effects were being published at that time, including a few from his laboratory. Prof. Raman suggested that the phenomena could be explained by treating the standing acoustic waves in the cell as a kind of diffraction grating causing phase changes in the traversing beam; the phase changes being due to density variations of the liquid associated with the compressions and rarefactions of the acoustic waves. A series of mathematical papers by himself and Nagendra Nath, where-in what is now called the Raman-Nath theory of diffraction of light by ultrasonic waves was developed.

During this period Prof. Raman's interest in diamonds renewed. He started work on a special type of X-ray reflections which were conspicuous in diamond. He concluded that in this phenomenon we are concerned with X-ray reflections of a second kind having a dynamic origin. He and his student collaborators made extensive studies of different kinds of crystals.

Several students who came to work under his guidance at Bangalore were provided with problems in optics such as : colours of striated media as are found in opals, shells, pearls, plumes of birds, optical effects of twinning of felspar, luminiscence of fluorspar, etc. Besides these, problems on light scattering and Raman Effect continued to be tackled in his Laboratories at Bangalore also.

On his superannuation from the Institute of Science, his activities shifted to the small Research Institute, which he himself established (see page 184). He collected a few students who soon after securing a degree, left him for "greener pastures" in USA. This made him sad and somewhat bitter. It was about this time that several bright young Indian scientists were emigrating to USA. He hurt and annoyed a large number of people by frequently saying that Indian Scientists were fast becoming "Camp followers of the West".

He devoted much of his time to understand the physical basis of the perception of colour by the human eye and the physiology of vision. He became a lone worker. His eyes, a direct vision spectroscope, flowers from his garden, and a few pieces of brightly coloured silk from the shops, constituted his apparatus and equipment. Several papers on Floral Colours and on Physiology of Vision flowed from his pen and were published. The main findings are;

(i) that plenty of illumination is required for the perception of colour.

(ii) that the presence of even a small intensity in the yellow part of the spectrum is a great physiological suppressor of the sensation of purity and richness of any other dye colour.

At his Research Institute (now called Raman Research Institute, and managed by a Trust) Professor Raman assembled an impressive museum comprising of a variety of minerals, crystals, iridiscent shells, feathers of birds, butterflies and many other items, in particular those which produce a sensation of colour.

For several years Professor Raman had made it a practice to deliver in the auditorium of his Institute the Gandhi Memorial Lecture on 2nd October of each year. On each of these occasions he chose an interesting scientific topic of general interest. The lectures were masterpieces in information content and scientific oratory. The last Gandhi Memorial lecture he delivered was on 2nd October 1970, the subject being "The Theory of Hearing."

9. Raman as a Teacher

Although it was not obligatory for a Palit Professor to participate in formal course work of the University, Professor Raman took a prominent part in teaching the M. Sc. students. He rightly held the view that when a research worker takes on some special teaching course, he brings to his teaching the freshness of research and the questioning attitude, which makes all the difference between dull pedagogy and inspired teaching. In listening spell-bound to Professor Raman's lectures on Electricity and Magnetism, his students shared with him much of the excitement and thrill that Oersted. Arago, Gauss, Faraday, Maxwell. Hertz, Lord Kelvin and many others must have felt while they were making their discoveries, It was no routine text-book learning. but reliving the actual evolution of the subject. After each lecture the students automatically went to the library to look up the original papers and the classical treatises like Maxwell's Electricity and Magnetism, J. J. Thomson's Conduction of Electricity in Gases, Faraday's Experimental Researches, Lord Rayleigh's and Lord Kelvin's. "Collected Papers".

In Physical optics the students were taught to induce them dip straight into the work of great masters like Huygens, Fresnel, Masscart, Schuster, Wood, Rayleigh and others. Thereby the students became imbued with real love and enthusiasm for the subject. Whether it was Thermodynamics, Kinetic Theory of Gases or Modern Physics, Professor Raman's treatment was original and inspiring.- He successfully demonstrated that teaching–learning–research–teaching, was a closely interlinked loop system, and that divorcing one from another would fail to achieve tangible results.

10. The Indian Academy of Sciences

One of the significant developments on a National scientific level which took place through the initiative and dynamism of Professor Raman, was the establishment of the Indian Academy of Sciences. The Academy was registered in April 1934, with distinguished men of science, drawn from the various parts of India and who were active participants in research work, as its Foundation Fellows. Professor Raman was elected Founder President and continued to be elected President of the Academy until his death in 1970. In the year of the foundation, he arranged, for the issue of the first number of the Proceedings of the Indian Academy of Sciences in two sections. one for Physical Sciences and the other for Biological Sciences. Thereafter, they were issued as regular monthly periodicals devoted to the publication of the results of research workers in India. Professor Raman put in great effort in getting the publications ready for distribution on the first day of every month during the 36 years of his Presidentship of the Academy.

It may be stated that the Academy noted early the potentialities of young scientists like Dr. M. S. Swaminathan, Dr. Sukhatme, Dr. S. Chandrasekhar and *encourged* them by being admitted into the Fellowship of the Academy, well before other scientific bodies recognised them and *rewarded* them with their Fellowship.

Professor Raman held the Annual Sessions of the Academy at a different University each year. The sessions lasted at least three days, with public lectures on all the three days, the first one being by the President himself. His purpose was to expose the young people in the University to the current research work done at the various centres, as well as to enable them to see the individual distinguished scientists in flesh and blood and to interact with them. This has been a very useful precedent set up by Professor Raman for promoting a scientific culture among the young aspirants of India. We are happy that the Academy is continuing this good practice.

Acknowledgments

Much of the material has been taken from :

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2. C.V. Raman. *S. Bhagavantam*
   Biographical Memoires of the Fellows of the Royal Society. Vol, 17. November 1971.
3. C.V. Raman, *L.A. Ramdas.*
   Physics Education.
4. C.V. Raman, *P.R. Pisharoty,* in the series
   Builders of Modern India, Publications Division, Ministry of I & B., Govt. of India.

Appendix-1

Fascimilie of Professor Raman's handwriting.

Appendix-2

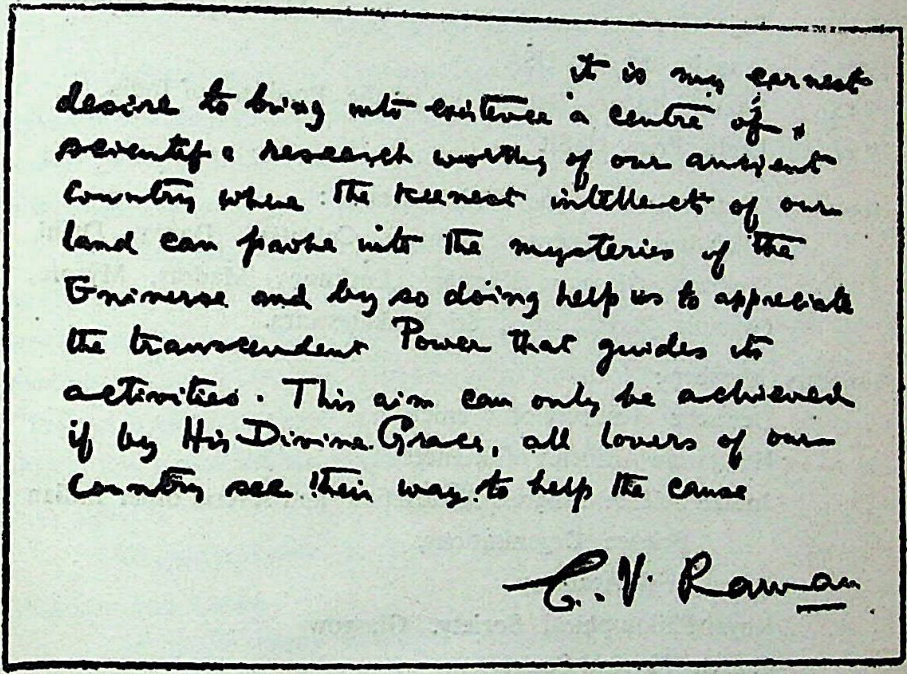
Honours Bestowed On Raman.

Appendix-3

Bibliography

Appendix - 1

The Principal objective of the Raman Research Institute, Bangalore in Raman's own handwriting. Obviously, Raman was not an atheist.



It is my earnest
desire to bring into existence a centre of
scientific research worthy of our ancient
country where the keenest intellects of our
land can probe into the mysteries of the
Universe and by so doing help us to appreciate
the transcendent Power that guides its
activities. This aim can only be achieved
if by His Divine Grace, all lovers of our
country see their way to help the cause

C. V. Raman

Appendix-2

HONOURS BESTOWED ON RAMAN

1924	Elected Fellow of the Royal Society, London.
1928	Matteucci Medal—Societa Instaliana Della Scienza. Rome.
1929	Knighted by the British Government in India.
1930	Hughes Medal—Royal Society, London.
1930	Nobel Prize—Stockholm, Sweden.
1935	Rajasabhabhushana–Decoration by the Maharaja of Mysore.
1941	Franklin Medal, USA
1945	Bharata Ratna—Decoration by the President of India.
1957	Lenin Prize, USSR

Honorary Doctorates from the Universities of :

Allahabad, Benaras, Bombay, Calcutta, Dacca, Delhi, Freiburg, Glasgow, Kanpur, Lucknow, Madras, Mysore, Osmania, Paris, Patna, Sri Venkateswara.

Honorary Member :

Deutsche Academy of Munich
Hungarian Academy of Sciences
Indian Science Congress Association and several other Indian Science Organisations,
Royal Irish Academy
Royal Philosophical Society. Glasgow
Zurich Physical Society.

Honorary Fellow :

Optical Society of America
Minerological Society of America

Foreign Associate :

Academy of Sciences, Paris

Foreign Member :

Academy of Sciences, USSR

Honorary Member :

Academy of the Socialist Republic of Romania
Catgut Acoustical Society.

General President :

Indian Science Congress. 1929

President :

Indian Academy of Science, 1934-1970.

National Professor :

Govt of India, 1960-1970

(*Appendix 3 A*)

BIBLIOGRAPHY

A detailed list of the published scientific papers of Prof. Raman is given in the *Biographical Memoirs of the Fellows of the Royal Society; London* (*1971*) on Chandrasekhara Venkata Raman, written by his distinguished student, Prof. S. Bhagavantam.

Prof. Raman was no narrow specialist. He had left his mark in several branches of Physics. During an active period of 65 years, commencing from a young age of 18, he published nearly 400 original scientific papers. A break-up of these papers under the different branches of Physics is given below to enable the reader appreciate the range of subjects this genius did successfully explore.

Wave Optics :

46 papers during the period 1906-1959

Vibrations and Sound

23 papers during the period 1909-1922

Theory of Musical Instruments

18 papers during the period 1914-1934

Colloid Studies

9 papers during the period 1909-1927

Molecular Scattering of Light

30 papers during the period 1919-1953

X-rays, Electron Diffraction and Crystal Optics

121 papers during the period 1923-1968

Magnetism and Magneto-Optics

11 papers during the period 1927-1931

Electro-Optics and Dielectric Behaviour
6 papers during the period 1926-1929

Raman Effect
17 papers during the period 1928-1932

Viscosity of Liquids and Surface Forces
8 papers during the period 1907-1928

Ultrasonic and Hypersonics
9 papers during the period 1935-1938

Line and Band Spectra
4 papers during the period 1922-1925

Optics and Elastic Properties of Solids
45 papers during the period 1918-1959

Physiology of Vision
85 papers during the period 1959-1970

Miscellaneous
9 papers during the period 1942-1968

Appendix—3 (B)

BOOKS

Molecular Diffraction of Light, 1922, Calcutta University Press.

The New Physics, Talks on Aspects of Science 1951. Philosophical Library Inc. 15 East 40th Street, New York

Lectures on Physical Optics : 1959, The Indian Academy of Sciences, Hebbal PO, Bangalore-6.

The Physiology of Vision : 1968, The Indian Academy of Sciences, Hebbal PO. Bangalore-6.

Besides the above, Prof. Raman has delivered several University convocation addresses. radio talks, and presidential addresses at numerous scientific associations and forums in India and abroad.

C.V. RAMAN AND THE GERMAN CONNECTION

S. RAMASESHAN

Chandrasekhara Venkata Raman (C. V. Raman) was one of the legends of Indian science. The discovery he made in 1928, the Raman Effect, for which he was awarded the coveted Nobel Prize, has never been surpassed in quality by any other made in India. His incredible career evokes many questions. What prompted him to do science at such a tender age? Where did he acquire such a passion for Nature which provided him the problems for his famous discoveries?

During his remarkable career Raman made many major scientific discoveries in such fields as acoustics, ultrasonics, optics, magnetism, X-rays. and crystal physics. His interests were wide, from astronomy and meteorology to physiology.

To a country that was fighting for independence and trying to establish its identity he became a symbol of its intellectual resurgence, to both young and old, because of the impact he made on the rest of the world. When he died in 1970, the President of India, S Radhakrishnan said.

"C. V. Raman was a great teacher. His knowledge was not confined to the physical sciences. In this overspecialized world his breadth of knowledge was remarkable. He combined the highest intellectual integrity with a winning warmth of heart...He was our most illustrious scientist who continued for many years to guide the scientific progress of India."

Raman and Helmholez

Raman had never been outside India till 1921. Yet what prompted him to pursue. with almost inexplicable vigour, modern science. which is considered by many to be a western implant? Apart from his native talent did anyone inspire him? I discovered recently a transcript of a speech by Raman entitled "The Books that Influenced Me" which gave one answer to this question.

Just as Raman dominated the Indian scientific scene in the first half of the twentieth century, Hermann von Helmholtz bestrode German science during the mid-nineteenth century. His wide ranging and exact work brought Germany to the forefront of world attention; a position she was to enjoy well into the twentieth century. Helmholtz was an inspiration to many. including his most distinguished student Heinrich Hertz, the discoverer of radio waves. There is no doubt that Raman too was inspired by Helmholtz. So great was this impact that young Raman actualiy puts von Helmholtz on par with the great Newton. He said in his speech :

"Speaking of the modern world the supremest figure, in my judgement, is that of Hermann von Helmholtz. In the range and the depth of his knowledge, in the clearness and the profundity of his scientific vision he easily transcended all other names could mention, even including Isaac Newton. Rightly he has been described as the intellectual colossus of the nineteenth century. It was my great good fortune, while still a student at college, to have possessed a copy of an English translation of his great work *The Sensations of Tone.* As is well known this was one of Helmholtz's masterpieces. It treats the subjects of music and musical instruments not only with profound knowledge and insight, but also with extreme clarity of language and expression. I discovered the book myself and read it with the keenest interest and attention.

It can be said without exaggeration that it profoundly influenced my intellectual out-look. For the first time I understood, from its perusal what scientific research really meant, and how it could be undertaken. I also gathered from it a variety of problems which were later to occupy my attention and keep me busy for many years."

Raman's researches on the musical instruments of India

It is said that orientalists owe the composer Mendelssohn much, as he dissuaded Max Mueller from devoting himself to his first love—

music! Max Mueller therefore turned to linguistics with his heart and soul and as a result could expound the culture of the east to the rest of the world. I think we owe it to Helmholtz that Raman took up the scientific study of Indian musical instruments and brought out some of the most unexpected aspects of their design. It was Raman's view that although music played an important role in the cultural life of ancient India, the material now available for writing its history is all too meagre. A better method of probing into the development of musical knowledge in ancient India would therefore be a scientific study of the musical instruments which have been handed down as heirlooms for untold generations.

The work of Raman on the musical drums of India is apochmaking and reveals the acoustical knowledge of the ancient Hindus—which is the title of a paper published by Raman. It was Pythagoras who first formulated what makes a sound seem musical to the human ear. If the string of an instrument is plucked (struck or bowed) it not only emits a note having a fundamental frequency, but also produces higher notes. If these overtones are in the ratio of the natural numbers (2,3,4 etc to the fundamental), the effect is musical, otherwise it is discordant or unpleasant. Scientifically it is well known that percussion instruments as a class can only produce inharmonic overtones and are therefore in a sense only noise makers. Raman's ear however detected that the Indian percussion instruments stand in an entirely different category in that they produce truly musical sounds. He showed that this was achieved by the partial loading of the drum membrane with a firmly adherent but flexible paste. As a consequence the Indian *mridangam* or *tabla* produces a succession of musically harmonic overtones in the same way as any stringed instrument.

The famed stringed instruments of India, the *vina* and the *tanpura*, are of undoubted antiquity and revered as a gift of the gods because their sound is considered closest to the human voice. Their tone exhibits a quality much superior to most "plucked" instruments. Raman made the surprising discovery that certain overtones, which according to acoustical principles should be entirely absent, sing out with great intensity in these instruments. He showed that the violation of what is called the Young-Helmholtz law is due to the curved bridge which the ancient Hindus had cunningly fashioned so that the *vina* (and the *tanpura*) could produce sounds richer in quality, worthy of Saraswati, the goddess of music whose favourite instrument it was.

Raman's acoustical studies were not confined to Indian musical instruments and they extended also to other western ones. While his wife was an accomplished *vina* player, it is hardly known that Raman himself was once a reasonably competent violin player. His mathematical theory of the bowed string and its experimental verification, his theory of how the impact of the hammer produces the exquisite vibration in the pianaforte and his demonstration of the peculiar Wolf Note produced by the violin and cello were all accepted and recognized by the experts of the musico-acoustical world. As a consequence he was invited to contribute to the *Handbuch der Physik* (published by Springer Verlag). This article entitled "Musikinstrumente and ihre Klange" (Musical Instruments and Their Tones) published in this prestigious German encyclopaedia of physics is considered an authoritative one on this subject. Raman wrote the article in English and it was translated into German. My attempts to get the original English version that Raman wrote for publication in "The Collected Works of C. V. Raman" were unsuccessful.

In the talk referred to earlier about Helmholtz, Raman greatly regretted that he could not read the other classic of Helmholtz—*The Physiology of Vision* "as it had not been translated into the English language", In the twenties Raman could read with facility scientific monographs written in German and he could even manage to speak the language (at least to non-Germans!). When he first went to the USSR, German was the only language of communication. The story goes that in Leningrad Raman, was shown by a professor a recent experiment he had performed on anomalous dispersion. On seeing it Raman exclaimed.

"Das ist sehr Schon. Aber ist esnicht Rozhdestvenskii-Experiment ?" (This is very beautiful; but is it not the Rozhdestvenskii experiment ?).

To which the Professor replied;

"Ja, Ich bin Rozhdestvenskii" (Yes. I am Rozhdestvenskii).

The blue of the sea

On his first journey to Europe in 1921 Raman was struck by the incredible beauty of the Mediterranean Sea and saw in it a vision of a vast world of knowledge awaiting his study. By performing an elegant but crucial experiment on board the ship (with optical components he had with him) he was able to disprove a conjecture made by Lord Rayleigh, that the blue of the oceans was due to the reflection of the blue skies in the waters. In 1922 he wrote the famous monograph *Molecular Diffraction of Light.*

There are two aspects of light. One is that it consists of electromagnetic oscillations (Maxwell and Hertz). The other is the complementary view propagated by two of the greatest scientists of this era, Max Planck and Albert Einstein, that it consists of particles (quanta) and that ceriatn observations like the photoelectric effect, incidentally discovered by Hertz, can only be explained on this basis In the monograph referred to above Raman says that if scattering of light is considered as a collision of a light quantum with a molecule many concepts derived from the classical wave theory may be violated.

Raman's discovery and the Kramers-Heisenberg theory

For the next six years Raman drove himself and his students to see whether these violations could be discovered. He finally succeeded on 28 February, 1928. It was shown that the light quantum and the molecule do exchange energy which manifests itself as a change in the colour of the scattered light. (Sometimes the light quantum gave a part of its energy to the molecule to excite it and the quantum was scattered with diminished energy and at other times it was scattered with greater energy by acquiring some from the vibrating or rotating molecule).

Historically, A Smekal in 1923 published a note in the journal *Naturwissenschaften* considering the quantitative aspects of the collision process that Raman thought of in his *Molecular Diffraction of* Light. Unfortunately, this paper was not noticed by experimental physicists including Raman and his group. Two years later, in 1925 Kramers and Heisenberg (two great names in European physics) developed Smekal's idea in a paper which is now considered one of the classics in physics. (It may be noted that Heisenberg was to invent quantum mechanics some of it based on this paper and to revolutionize physics there by). Their paper contained many beautiful but complex ideas, but again their experimental implications were not obvious nor were they made clear in the paper. However, Raman seems to have perceived their import. In fact, when hot on the trail (three weeks before the actual discovery of the Raman Effect) K. S. Krishnan, *the* major collaborator of Raman writes in his diary:

February 7th Tuesday; Professor (Raman) came to the house about 9.00 pm—and called for me. We (Venkateswaran and Krishnan) went down. We found him very excited and he had come to tell me that what we had observed that morning must be Kramers–Heisenberg process we had been looking for all these days We therefore, agreed to call the effect MODIFIED SCATTERING."

The visit of Arnold Sommerfeld to Raman's laboratory

Sommerfeld the renowned German physicist, author of the classic *Atombau und Spectrallinien*, and who shaped theoretical physics in Germany by the style of his lectures and his remarkable qualities as a teacher, decided to go to the United States through the eastern route (via India). He was.

"...especially attracted by the wonderful land of India because of its exotic buildings. fantastic religions with their philosophical systems; and also because it was in this ancient land that during the last few years strong shoots of modern physics had grown by which India suddenly emerged in competition in research as an equal partner with her European and American sisters."

About this it is said:

"Sommerfeld was thinking of the spectroscopic effect discovered by Raman which like no other discovery attracted attention and enthusiastic cooperation all over the world."

When Raman heard of Sommerfeld's intention to take the eastern route he sent a telegram (11 February, 1928).

"Calcutta University inviting you, lecture honorarium thousand rupees. Kindly wire date arrival India,"

As soon as Sommerfeld arrived in India (as is not unusual with foreigners !) he took ill and spent two weeks in a hospital in Bangalore. On 4 October, 1928 he arrived in Calcutta and on the same day visited Raman's institute (IACS). Raman showed how using light and a small spherical ball he was able to verify some of the theories of Sommerfeld on the propagation of radio waves round the Earth ! Wrote Sommerfeld;

"Everything in the institute very good; but bathrooms terrible."

Sommerfeld's visit to India was, in my view, very significant as he was the first discriminating scientist to come to Raman's laboratory and to see the demonstration of the new discovery. There were some who have even later expressed some scepticism as to whether Raman could have observed his effect visually as the intensity of the Raman Scattering would be only a hundred millionth that of the incident light. They could not imagine the power of sunlight in India which was why Raman chose it for his studies nor did they reckon with the ingenuity that is evoked when a man of genius is short of funds and equipment !

On 6 October, Sommerfeld "eventually saw the Raman Effect visually..." On Sunday 7 October, he heard "a wonderful lecture by Raman—also that the rotations of molecules can be seen (unresolved) as the modified radiation" and on subsequent days "saw the blue green in an ice block—obviously modified scattering". Indeed so convinced was, Sommerfeld of the reality of the Raman Effect that he proposed Raman as a candidate for the Nobel Prize. There were at least 10 others who also proposed his name for the Nobel Prize.

Sommerfeld after a serious conversation with Raman comments critically on India's economic and political conditions and her difficult relations with Great Britain. He left India

"with deepest affection for the highly gifted but unhappy nation with sincere gratitude for many acts of friendliness and honours bestowed on him".

Sommerfeld and Raman became very good friends. On his way back from receiving the Nobel Prize in 1930 Raman visited Sommerfeld in Munich. He was received with great joy.

"We welcome our guest not only as a successful scientist and discoverer but also as a representative of the age-old and now rejuvenated culture of the orient which trustfully cooperates with the occidental culture and strives for the same ends."

It is not so well known that S. Chandrasekhar the astrophysicist (also a Nobel Prize winner), when just 18 years old, met Sommerfeld in Madras during his 1928 visit to India. They discussed the new developments made by Sommerfeld on the theory of metals where be had used Fermi-Dirac statistics. Chandrasekhar went on to extend this to the case of stars which led to one of his important discoveries.

Among the other visitors to the IACS were von Karman in the summer of 1928 and Heisenberg (1929) when he was not yet 28. Unfortunately. I have not been able to get authentic accounts of these visits.

The Raman Effect – Pringsheim

The possibility of the existence of the effect discovered by Raman was obviously inherent in the Kramers–Heisenberg paper and in quantum mechanics. As Born says in 1928 just six months after the discovery:

"Raman's discovery is predicted in its entirety by quantum mechanics and could be thought of as a proof for the same."

Then one can ask whether a dozen distinguished men of science proposed Raman to the Nobel Prize just because he found a proof for quantum machanics. The answer is a definite No. One thing is quite clear—that the implied prediction was obscure even to the theorists and definitely so to the experimenters at that time. The discovery did come as a surprise to everyone. We see an element of this in what Einstein said :

"C. V. Raman was the first to recognize and demonstrate that the energy of a photon can undergo partial transformation within matter. I still recall vividly the deep impression that this discovery made on all of us..."

In August 1928. Prof Peter Pringsheim of the Berlin University published a paper in *Naturwissenschaften* which reported a detailed study (done with the proverbial German thoroughness) of the various then known scattering processes and concluded :

What has been discovered by Raman is an entirely new phenomenon worthy of being designated "The Raman Effect" and the spectrum of new lines associated with it as "The Raman Spectrum" .

"One can state without doubt that through his discovery Raman has opened up a vast and completely new field of spectroscopy."

This was possibly the reason why the Raman Effect was so enthusiastically welcomed and commended by the leaders of science.

Laue aufnahmen or Laue Photographs

The results coming out of Raman's laboratories were so profuse that he needed journals near at hand to publish all of them. In his early days in Calcutta he founded the *Proceedings of the Indian Association for the Cultivation of Science* (1917) and later the *Indian Journal of Physics* (*1926*). When he moved to Bangalore he started the *Proceedings of the Indian Academy of Sciences* (1934). He has been closely connected with *Current Science* since its founding in 1932, All these journals are till doing well, One of the greatest discoveries of modern physics was the diffraction of X-rays by crystals by Max von Laue. When *Current Science* decided to bring out a special number in 1937 to commemorate the silver jubilee of this discovery it was a collaborative effort between India and Germany. Dr Adolf Berliner, the editor of *Naturwissenschaften* and Prof. Max Born took special interest in this issue and used their personal influence with their friends to get special contributions. The result was that a galaxy of scientists sent in articles—among the authors were Laue himself (Germany), William and Lawrence Bragg (UK) who were responsible for so much development of the X–ray crystal structures of inorganic, organic, mineral and metallic materials, Ewald (Germany/US) who was associated with X-ray crystallography even before its discovery and has done so much for its growth, Manne Siegbahn (Sweden) who made X-ray spectroscopy into a precise and quantitative field, Linus Pauling (US) who made the remarkable connection between X-ray structures with chemistry and biology, Hermann Mark (Germany/US) who started as an X-ray physicist but did pioneering work on polymers and J. A. Prins (Germany) who elevated the qualitative theory of X–ray diffraction of liquids developed by Raman and his school to a precise quantitative one.

In his introduction Raman thanks these leading authorities in X-ray physics for their contributions and pays tribute to two outstanding experimental discoveries made in Germany :

"Students of optics recognize in Prof. Laue a great exponent of their science. While the work of Hertz opened up the possibility of communication with *distant space*, Laue's work brought the submicroscopic world within the range of direct observation."

Laue (in 1912) discovered that when an X-ray beam is diffracted by a crystal this geometric diffraction pattern can be registered on a photographic plate. Such patterns have been called by generations of crystallographers as Laue aufnahmen—Laue Photographs.

A meeting was held in 1948 in Boston (USA) when a large number of scientists of the world gathered to decide on the establishment of an International Union of Crystallography. On one of the days many scientists were relaxing at a beach near Boston. Amongst these were some well-known ones, von Laue, Lawrence Bragg, Paul Ewald, Raman, Patterson, Hermann Mark, J. D. Bernal and others. A young lady with a camera rushed to get a photograph of von Laue wearing very brief swimming trunks. Seeing this Raman quipped to Ewald "She is trying to get the real Laue aufnahmen" Paul Ewald was so impressed with this spontaneous pun that he related this to many (including to me 6 years later when I was with him at Brooklyn Polytechnic).

The Indian Institute of Science

In 1933 Raman was appointed Director of the Indian Institute of Science (IISc). This Institute was set up in 1909 with the main objective of pursuing original research and providing advanced training in science and engineering. To J. N. Tata, the visionary, such an institution was to be the primary base for the intellectual rejuvenation and modernization of India. But to Lord Curzon–the then Viceroy of India, this was a seditious step against the British Raj and so he opposed its establishment. Nevertheless, five years after Tata's death. the IISc was established and that too in Bangalore because of the farsightedness of the Maharajah and the Government of Mysore who offered it nearly 150 hectares of land and many other facilities.

The Directors of the Institute (till Raman's appointment) were always British and so were most of the earlier faculty. Some felt that under the tutelage of the British "Resident" of the Mysore State, IISc was subserving the interests of Great Britain, and that even the starting of the General Chemistry and Electrical Technology Departments were connected with the running of the British—owned Kolar Gold Fields.

"But such is the irresistible nature of truth that all it asks and all it wants is the liberty of appearing." What Thomas Paine said of truth is equally applicable to education. The effect of research and education "appearing" at IISc had a tremendous effect on the country. Nationalists however were dissatisfied with the "performance" of thei nstitute—that in spite of large sums of money spent neither did the institute catalyze industrial growth nor did any outstanding scientific discoveries of which India could be proud, come out.

When Raman was to move to Bangalore it was said :

"At present Calcutta may be regarded the centre of scientific research in India. With the transference to Bangalore of one of the leading investigators Calcutta will have to guard its laurels."

Raman's invitation to German professors

The money spent on science in Calcutta was paltry compared to that spent at the Institute. Raman felt strongly (rightly or wrongly) that research and advanced education can be the foundation for any economic advancement only if there was excellence of the highest order. So Raman tried many strategies for bringing this about at IISc.

The first was to improve the surroundings (not just the houses of the director and the professors) by planting beautiful flowering trees—and in this he was aided by Sir Mirza Ismail, the Diwan of Mysore, and Mr Krumbeigel, the Chief Horticulturist of Lal Bagh.

The second was to set up a central workshop to make instruments (for it was Raman's view that no real progress in science can be made using *only* imported instruments). Precision instruments must be fabricated inside the country.

The third was to set an example of doing quality research With a team of talented students he (again) blazed new trails in many fields—ultrasonic diffraction, Brillouin scattering, colloid optics, spectroscopic and optical properties of crystals, crystal transformation, X-ray topography and scattering, etc and put IISc on the scientific map of the world (some say for the first time in its 25 years of existence).

The final method was to fill important gaps in knowledge by recruiting outstanding faculty; Raman had a long list of subjects—some of these were : quantum mechanics (which was revolutionising physics): radioactivity (which was setting the pace in inorganic and biological chemistry) : crystal chemistry (which was the basis for the development of modern materials so essential for India) : vitamin and enzyme chemistry (which was making big waves in organic and biochemistry). Raman felt that the basic research in these fields will generate applications which would be important for India's development.

It was at this time that many reputed scientists were fleeing Germany to escape the tyranny of Adoll Hitler---and Raman wanted to invite them to India ;

"I was not much in favour of young Indians going abroad to be initiated into scientific research. For if they are trained in completely alien atmosphere not available in India the training may not prove useful. But if savants; seeking a country to adopt, are provided with a home we could start a great scientific movement,"

It appeared to be an excellent idea as witness the renaissance of science in the United States which took place by the same process that Raman tried to adopt for India.

Raman first wrote to Schroedinger, the discoverer of wave mechanics, the physicist philosopher and author of *The Meaning of Life*. He replied saying that Raman's offer reached him after he had received and accepted another from Dublin, Ireland (although Raman's letter was posted earlier). Thus he has unfortunately "to miss the opportunity of being in the land of Upanishads".

Georg von Hevesy of the University of Freiburg, a pioneer in the use of radioactive tracers to follow chemical reactions and the movement of chemicals in human tissue, actually accepted the offer but did not come because of the later events related below.

For crystal chemistry V. M. Goldschmidt, perhaps the greatest authority in this field was invited. He too accepted the offer but did not come probably for the same reasons.

Raman had many names on his list, both foreign and Indian, and it is a commentary on his choice that many of them (including Hevesy and Born) received the Nobel Prize many years later.

The visit of Max Born

Max Born was among the most outstanding theoretical physicists of this century. He developed the theory of atomic structure, worked on the early versions of the quantum theory (Bohr-Sommerfeld) and saw it blossom into quantum mechanics in the hands of Heisenberg.

Raman first requested Born to suggest the name of a young theoretical physicist for an appointment at IISc but later invited Born himself to spend six months to lecture here. Born and Mrs (Hedi) Born arrived in India in autumn 1935. Born had this to say of his first impressions :

"We liked Lady Raman right from the beginning. When Raman appeared later we were fascinated by his appearance and talk. To Hedi he looked, in his Indian dress and turban, like a prince from *The Arabian Nights.*"

Max Born enjoyed his stay and his lectures were appreciated widely. To Lord Rutherford he wrote saying :

"I most frankly say I like him (Raman) very much inspite of his all too human drawbacks, his conceit and his naivete and therefore his disarming way of bringing himself into the light. I do not take these too seriously as I am finding (on the other hand) a genuine devotion to his work and to the Institute. He is an excellent physicist, full of optimism and activity and besides being interested in everything in the world".

Born interacted not only with Raman but also his students and all seem to have enjoyed it thoroughly. One of his student collaborators wrote of Born:

'It is amazing to speculate how profoundly a great scientific mind can influence those coming in contact...A most eminent physicist alike in the depth of mathematical power...a teacher whose encouragement and kindness to his students is unparalleled."

And Lady Raman looked after their other activities. Born said :

"Life was pleasant for us, Hedi enjoyed it even more than myself. She met a Swami of the Ramakrishna Order and they became great friends, He told her that she had been an Indian woman in her previous incarnation because she understood Indian spiritual life so well."

So Raman decided to offer a permanent position to Max Born at the Institute. A selection committee was constituted and at Raman's suggestion Lord Rutherford was made a member ⅄ Chairman (?) who had no difficulty in putting Born's name first among those recommended for selection. Rutherford conveyed this information to Born who decided to accept the offer.

"While we would have liked to have had your services in Cambridge. I feel that the new position is not only very much better paid, but offers you an opportunity of influencing science in India. In this way I think you can exert a much wider personal influence for good than if you remained in Cambridge where you are one of a number and where possibly missionary work in the scientific flield is not so important. Altogether, I feel you have made a wise decision."

All seemed to have been settled but.,...At the Council where this decision was to be ratified Raman spoke of the extraordinary merits of Born as a scientist, as a teacher, and as a human being. Then something quite unbelievable actually happened. An engineering professor from England who was rejected for an academic position even in England and whose name means nothing today even at IISc, spoke in the most derogatory fashion about Born—referring to him as a second rater who had been driven out of his own country and one not good enough to be a member of the faculty of the Indian Institute of Science ! So low had the British faculty at IISc descended.

After this public insult, of course, Born felt he could no longer accept Raman's offer and Raman too lost all hopes of rejuvenating the Institute in such a hostile atmosphere.

Why did Raman fail so miserably ? There are many views expressed in this connection some of which I quote. Born himself said:

"Raman came to the Institute with the idea of making it a centre of science of international standard. What he found was a quiet sleepy place where little work was done by a number of well-paid people... Raman's speeding up of the entire pace of the Institute was bound to look like criticism of the former management. He made the heavy (sic) mistake in not waiting for a year or two before starting actual reforms,"

"Raman was obviously surrounded by people both British and Indian who largely looked upon IISc as a source of sinecure positions."—Born

"Some of the English faculty resented working under Raman—an Indian—an experience they never had before."—Born

"The faculty members had gained the ear of the colonial Government which agreed to put pressure on the Tata family."

"All changes made by Raman provoked resentment and many felt that physics was in the process of becoming a dominant feature of the Institute."

"Raman far too conscious of his own superiority, made other people feel small in his presence."

"Raman with an astute mind and sharp tongue seemed to provoke resentment and tension round him."

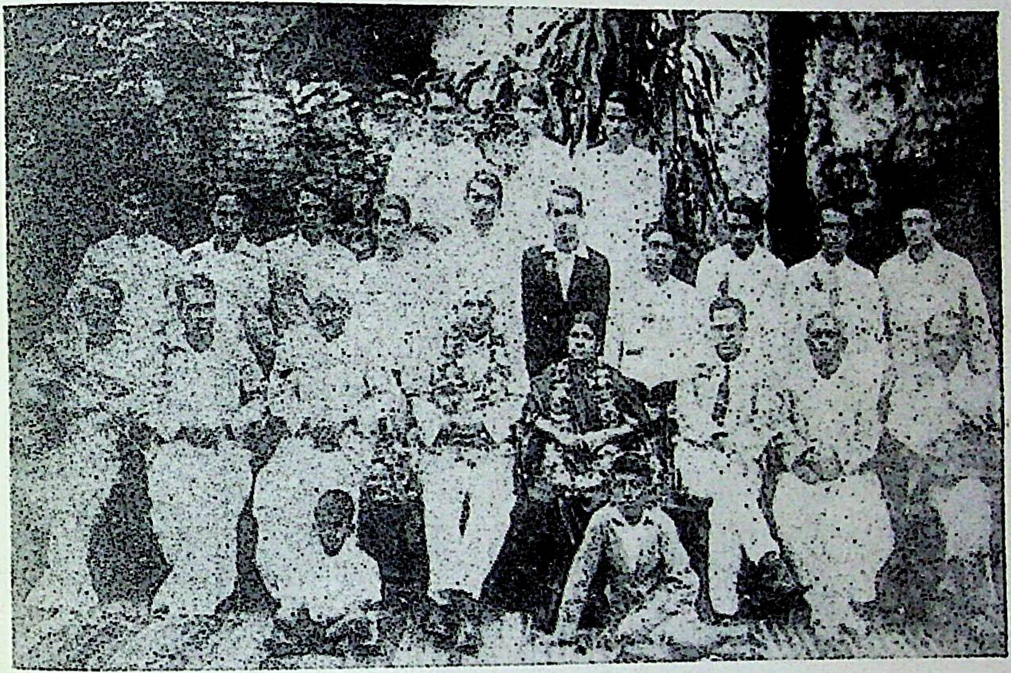
"There is no Indian physicist of the rank of Raman. No man can compare with him in regard to vigour or intensity. This European intensity which Raman exhibited to a marked degree seemed to make many Indians suspicious of him."—Born

Everything he tried to do was considered wrong and he had to resign his directorship (but retained his professorship at the Institute) It is a matter of great regret to many that Raman and Born who were such great friends fell out much later on a scientific issue. It is Born's view that the above regrettable incident rankled in Raman's mind which probably led to this unfortunate rupture.

The Raman Research Institute

Raman retired as Professor from IISc in 1948. He wanted to start a small institute for himself (the Raman Research Institute) where he could retire and "enjoy" doing science with a few collaborators. This he hoped to do with his life's savings; but it so happened that he lost most of his savings (including the Nobel Prize money) in a South Sea Bubble like investment. Undaunted, he proceeded and we see yet another European connection. He knew that while in most countries incandescent lamps were the rule, there were others in the East which still used kerosene and other lanterns and where lighting of streets in many cities was still done with gas (for example, Calcutta and cities in the Malay peninsula). With the aid of a student with a chemistry background he had launched courageously into setting up a Welsbach mantle factory. Welsbach (1858-1929) discovered that a fabric soaked in thorium nitrate and cerium nitrate (both chemicals available in India) when heated glows with great brilliance. (Some of Raman's researches drew his attention to this fact.) The product from Raman's factory sold well, and the dividends from this venture were substantial. In fact they were sufficient to support his Institute and keep it independent at a time when he decided for good reasons, not to accept even marginal support from Government.

The growth and the blossoming of the Raman Research Institute is another story,



Prof. Raman being given a hearty send off in 1930 on the eve of his departure from Calcutta to receive the Nobel Prize. (Lady Raman and Prof. Raman's sons are in the picture.)

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RAMAN EFFECTS AND THEIR APPLICATIONS

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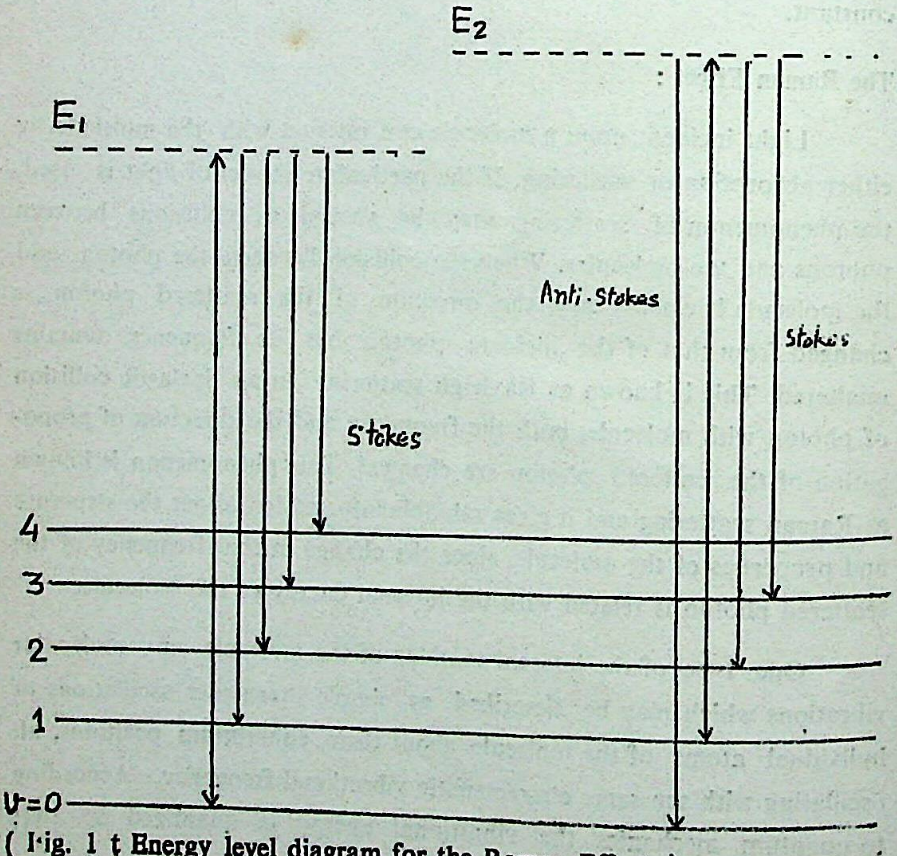
Light is regarded as both wavelike and particle-like at the same time. In its wave description light may be described by fluctuating electric and magnetic fields at right angles to each other in a plane perpendicular to its direction of propagation. In the particle description, light is considered as a stream of photons each with energy $h\nu$ where ν is the frequency of light in its wave description and h is the Planck's constant.

The Raman Effect :

Light incident upon a molecule can interact with the molecule by either absorption or scattering. If the particulate model of light is used, the phenomenon of scattering may be viewed as collisions between photons and the molecules. When the collision between the photon and the molecule is elastic, only the direction of the scattered photon is changed from that of the incident photon but its frequency remains unaltered. This is known as Rayleigh scattering. In an inelastic collision of photon with molecule, both the frequency and the direction of propogation of the scattered photon are changed. This phenomenon is known as Raman scattering and it gives valuable information about the structure and properties of the molecule, since the change in the frequency of the scattered photon is related with the internal energy of the molecule.

One type of the internal motions of the molecule are molecular vibrations which may be described as simple harmonic oscillations of individual atoms of the molecule about their equilibrium positions, all oscillating with the same characteristic vibrational frequency. According to quantum mechanics the vibrational energy is quantized so that molecules may have one or the other discrete energy states characterized by a vibrational quantum number V. The lowest vibrational state of a molecule is characterized by $V=0$ and vibrational energy states of increasing energy are represented by $V=1, 2, 3$ etc.

Raman scattering is schematically depicted in Fig. 1. Interaction of the photon of energy $h\nu$ with a molecule in the lowest vibrational state ($V=0$) momentarily increases its energy to that of a virtual state E_1 which has lifetime of the order of 10^{-17} secs. This is called a virtual state since it is a unstable state of both the photon and the molecule. The molecule may return from this virtual level to any of its real vibrational levels characterized by $V=0, 1, 2, 3$ etc. The return of the molecule to the state with $V=0$ is accompanied by creation of a photon of same energy as the incident photon and the process is called Rayleigh scattering, If the molecule returns from the virtual



(Fig. 1 t Energy level diagram for the Raman Effect.)

state E_1 to the vibrational state with $V=1$ or 2 or 3 etc, then the energy of the scattered photon is less than that of the incident photon and hence its frequency is also less than that of the incident photon. This type of Raman scattering is called Stokes' Raman Scattering,

The interaction between a photon of energy $h\nu$ and a molecule in the excited vibrational state with $V=1$ leads to a virtual state represented by E_2. This virtual state is similar to E_1 except for the fact that its energy is equal to the sum of the vibrational energy of molecule and the energy of the photon. The molecule may again return to any of its vibrational states. If it returns to the state $V=0$, the energy of the scattered photon is more than that of the incident photon and the process is called Anti-Stokes-Raman Scattering. The return of the molecule from E_2 to $V=1$ does not involve any change in the energy of scattered photon from that of the incident one and leads to Rayleigh scattering. If the molecule returns to the states with $V=2$ or 3, etc. the energy of the scattered photon is less than that of the incident photon and the process is Stokes-Raman Scattering.

It may be seen from the above description that the difference between the energy of the incident photon and that produced in Raman scattering is always equal to the energy difference between two vibrational states of the molecule. In a general situation if the scattered radiation is analysed with a spectrometer, one observes, in addition to the frequency of the incident radiation, several Stokes Raman frequencies and Anti-Stokes-Raman frequencies.

Molecular Polarizability :

A molecular vibration leads to scattered radiation at a frequency different from that of incident light if the electric polarization of the molecule changes due to the vibration. To understand the physical meaning of polarizability of a molecule let us consider a CCl_4 molecule which is spherically symmetric and which does not have a permanent dipole like that in H_2O molecule. If CCl_4 molecule is placed between oppositely charged plates the electron cloud of this symmetrical molecule becomes distorted and a separation of centroids of positive and negative charges occurs. Changing the polarity of the plates causes a change in the direction of the distortion of electron cloud and periodic alterations result in a vibrating induced dipole. Analogously, the fluctuating electric field of a light wave impinging on a molecule induces a dipole moment that vibrates with the same frequency as the incident light.

In the wave picture of light, the scattered radiation arises from electromagnetic waves emitted by a vibrating dipole and its intensity is dependent on the polarizability of the molecule. The polarizability of a molecule is due almost entirely to displacements of the electron cloud under the influence of the oscillating field of the incident light beam. The induced dipole moment is given by

$$\vec{\mu} = \propto \vec{E} \qquad \cdots(1)$$

where $\vec{E}$ is the electric field of the light wave and $\propto$ is the polarizability of the molecule. Most of the molecules are anisotropic i. e. they are not spherically symmetric and thus the moleeular polarizability has different values in different directions. In such a situation the components of the induced dipole moment along the coordinate axes x, y and z are given by the following relations

$$\begin{aligned} \mu_x &= \propto_{xx} E_x + \propto_{xy} E_y + \propto_{zx} E_z \\ \mu_y &= \propto_{yx} E_x + \propto_{yy} E_y + \propto_{yz} E_z \qquad (2) \\ \mu_z &= \propto_{zx} E_x + \propto_{zy} E_y + \propto_{zz} E_z \end{aligned}$$

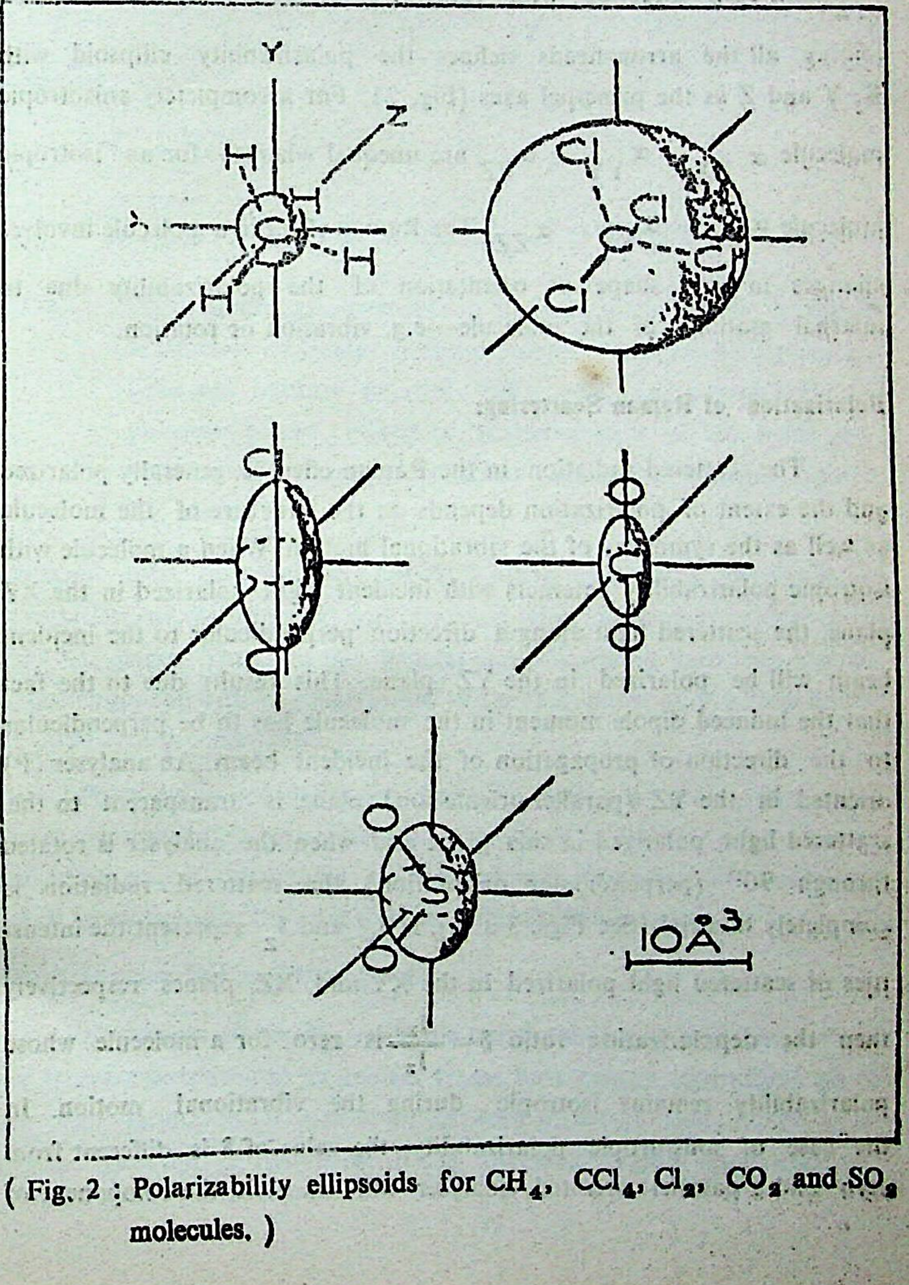
The molecular polarizability $\propto$ is thus a tensor with components $\propto_{xx}$, $\propto_{xy}$ etc. In most cases the polarizability tensor is a symmetric one so that.

$$\propto_{xy} = \propto_{yx}, \quad \propto_{yz} = \propto_{zy} \text{ and } \propto_{zx} = \propto_{xz}$$

It is a mathematical property of symmetric tensors that for a special set of three mutually perpendicular axes. X, Y and Z its components with only identical suffixes are different from zero and equation (2) may be written as follows

$$\mu_X = \alpha_{XX} E_X$$

$$\mu_Y = \alpha_{YY} E_Y \qquad (3)$$



Y
Z
X
H
H
H
H
C
Cl
Cl
Cl
Cl
C
Cl
Cl
O
C
O
O
S
O
$10\mathring{A}^3$

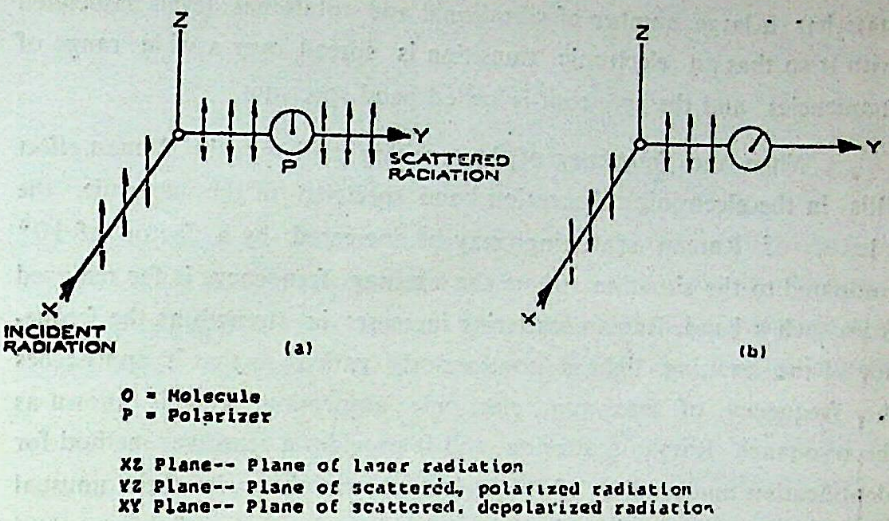
(Fig. 2 : Polarizability ellipsoids for CH_4, CCl_4, Cl_2, CO_2 and SO_2 molecules.)

$$\mu_Z = \alpha_{ZZ} E_Z$$

X, Y and Z are called principal axes of polarizability and the equilibrium molecular polarizability can be visualised by drawing arrows from the centre of mass of the molecule with lengths poportional to $\frac{1}{\sqrt{\alpha i}}$ in each direction with value of polarizability α_i. The surface joining all the arrow-heads defines the polarizability ellipsoid with X, Y and Z as the principal axes (Fig. 2). For a completely anisotropic molecule α_{XX}, α_{YY} & α_{ZZ} are unequal whereas for an isotropic molecule $\alpha_{XX} = \alpha_{YY} = \alpha_{ZZ}$. The Raman effect in a molecule involves changes in size, shape or orientation of the polarizability due to internal motions of the molecule—e.g. vibration or rotation.

Polarization of Raman Scattering:

The scattered radiation in the Raman effect is generally polarized and the extent of polarization depends on the structure of the molecule as well as the symmetry of the vibrational motion. When a molecule with isotropic polarizability interacts with incident light polarized in the XZ plane, the scattered light along a direction perpendicular to the incident beam will be polarized in the YZ plane. This results due to the fact that the induced dipole moment in the molecule has to be perpendicular to the direction of propagation of the incident beam. An analyser (P) oriented in the YZ (parallel orientation) plane is transparent to the scattered light polarized in this plane and when the analyser is rotated through 90° (perpendicular orientation) the scattered radiation is completely blocked (See Figs. 3 a. b). If I_x and I_z represent the intensities of scattered light polarized in the XY and XZ planes respectively then the depolarization ratio $\delta = \frac{I_x}{I_z}$ is zero for a molecule whose polarizability remains isotropic during the vibrational motion. In the case of anisotropic polarizability the value of δ is different from zero and a parallel oriented analyser will transmit, the component of


Z
Y
P
SCATTERED RADIATION
X
INCIDENT RADIATION
(a)
Z
Y
X
(b)
O = Molecule
P = Polarizer
XZ Plane-- Plane of laser radiation
YZ Plane-- Plane of scattered, polarized radiation
XY Plane-- Plane of scattered, depolarized radiation

(Fig. 3 : Polarization measurements in Raman scattering (a, b) totally symmetric molecular vibration interacts with incident polarized light and scatters palarized light only. (a) parallel oriented polarizer allows passage of scattered light in YZ plane (b) : perpendicular-oriented polarizer does not transmit light in YZ plane.)

scattered light polarized in the YZ plane whereas a perpendicular orientation of the analyser will transmit the component polarized in the XY plane. Thus, in the general case, scattered light has a polarized component with its polarization in the YZ plane and a depolarized or unpolarized component.

Polarization of light in Raman scattering gives information about the symmetry of molecular vibrations in liquids, gases, crystals and polymers. It also helps in the determination of phase changes in liquid crystals and solids when these substances are heated.

The Resonance Raman Effect (RRE):

The energy states of a molecule corresponding to different electronic arrangements around its nuclear frame have energy separations which are very large, and a transition between a pair of such states gives rise to spectrum in the visible or the ultraviolet region. Each electronic state has a large number of vibrational and rotational levels associated with it so that an electronic transition is spread over a wide range of frequencies and the spectrum is called band spectrum.

When the frequency of the exciting radiation in Raman effect falls in the electronic absorption band spectrum of the molecule, the intensity of Raman scattering may be increased by a factor of 10^6 compared to the situation where the exciting frequency is far removed from such a band. Raman scattering increases in strength as the frequency of the exciting light is continuously varied so that it approaches the frequency of maximum electronic absorption. This is known as the resonance Raman scattering and it provides a sensitive method for identification and studies of biological chromophors in their unusual dilutions (about 10^{-2} - 10^{-5} molar). Applications of this method includes studies of carotenoid pigments, vitamin-A type molecules, rubridoxin, hemoglobin, oxyhemoglobin, de-oxyhemoglobin, cytochrome C, porphyrines and bacteriorhodopsin etc. In some cases this method can be used to obtain the spectrum of an impurity at ultra low concentrations.

Nonlinear Raman Effect :

A number of phenomena related to the Raman effect occur when one or more high power lasers are used as the source of excitation. The first such effect was observed in nitrobenzene excited with a ruby laser at 6943 A which gave rise to Stokes radiation at 7650A with an intensity of over 25% of the ruby light and propagating in a direction almost colinear with the incident laser beam. The scattering processes of this type are generally known as Stimulated Raman Scattering and they result because of non-linear response of the medium at very high intensities of exciting radiation.

The theoretical description of nonlinear Raman processes may be explained more conveniently in terms of the net polarizability $\vec{P}$ of an ensemble of molecules which is related to the electric field $\vec{E}$ of the electromagnetic radiation through the susceptibility tensor χ as follows:

$$\vec{P} = x \vec{E} \qquad \dots(4)$$

This may be compared with the induced dipole moment $\vec{\mu}$ of a single molecule as given by equation (1). Both equations (1) & (4) assume the molecular distortions caused by the external field $\vec{E}$ to be sufficiently small so that the bond energies are not changed. At higher fields associated with very intense laser radiations this approximation breaks down and there is no longer a linear relationship between $\vec{P}$ and $\vec{E}$. A saturation of polarization must be reached and eventually the material must undergo dielectric breakdown. To take account of this nonlinear behaviour the polarization is written as a Taylor series

$$P = x^{(1)} E + x^{(2)} E^2 + x^{(3)} E^3 + \qquad \dots \dots (5)$$

in the electric field where $x^{(i)}$ represents the 'ith' order susceptibility. It is important to recognize that equation (5) is simply a convenient method for expressing the distorted polarization since there is no analytical solution for the relationship between $\vec{P}$ and $\vec{E}$. It is more convenient to use angular frequency $w = 2\pi\nu$ to describe the radiation fields. The first order term $x^{(1)}$ leads to the ordinary or the spontaneous Raman effect. The term involving $x^{(2)}$ involvesa product of two electric vectors and leads to hyper-Raman effect where incoherent scattering at $(2w \pm w_v)$ occurs where w_v represents the vibrational frequency and w represents the laser frequency. Coherent scattering is caused by the third order susceptibility $x^{(3)}$ that couples three electromagnetic waves to produce a fourth wave. Let us assume that there are two incident laser beams with frequencies w_L and w_S ($w_L > w_S$) propagating in a molecular medium at a small angle with each other and coherently excite a molecular vibration of frequency $w_V = w_L - w_S$. In such a situation of resonance the two light waves produce a beat frequency $w_L - w_S$ which in turn may interact with the third light wave at either w_L or w_S to produce the sum or difference frequencies. The polarization of the medium may oscillate with frequencies $w_A = (2w_L - w_S)$, $w_C = (2w_S - w_L)$. w_L or w_S which causes coherent-scattering at these frequencies. When the intensities of scattered beams at w_A and w_C are large, generation of light waves at higher frequencies (e. g. $3w_L - 2w_S$) may result by further mixing processes. These higher order scattering processes are called, Higher Order Raman Spectral Excitation Scattering (HORSES). The scattered radiation beam with frequency $2w_L - w_S$ is called coherent Antistokes Raman Scattering (CARS) and that with frequency $2w_S - w_L$ is known as Coherent Stokes Raman Scattering (CSRS). The scattered beams with frequencies w_L and w_S are known as inverse Raman scattering & stimulated Raman scattering respectivaly.

Coherent Antistokes Raman scattering (CARS) was first observed in 1965 in a high intensity coherent directional beam that was separated in space from the excitation beams and was easily detected. Since the anti-Stokes beam is coherent and directional it can be easily isolated from the incoherent fluorescence in the medium (if any) by spatial filtering. In addition the wavelength of the anti-Stokes beam is on the low side of the excitation wavelengths where it is difficult to get fluorescence. These properties of CARS has made it a valuable tool for many investigations in pure and applied science.

Surface Enhanced Raman Scattering

When a molecule is appropriately adsorbed on or near a metal surface its Raman scattering efficiency is increased by factors of 10^3 to 10^6. Such enormous enhancement of normal Raman scattering has revolutionised the field of surface science where one would like to have directly interpretable detailed information on one or more of the following :

(1) the structure and orientation of adsorbed molecules.
(b) the strength and nature of surface chemisorption bonding
(c) the structure of surface active sites and catalytic reaction intermediates

(d) the dynamics of surface chemical reactions.

There are several theoretical explanations for the surface enhanced Raman scattering but the one that explains many of the observed features involves the following mechanism.

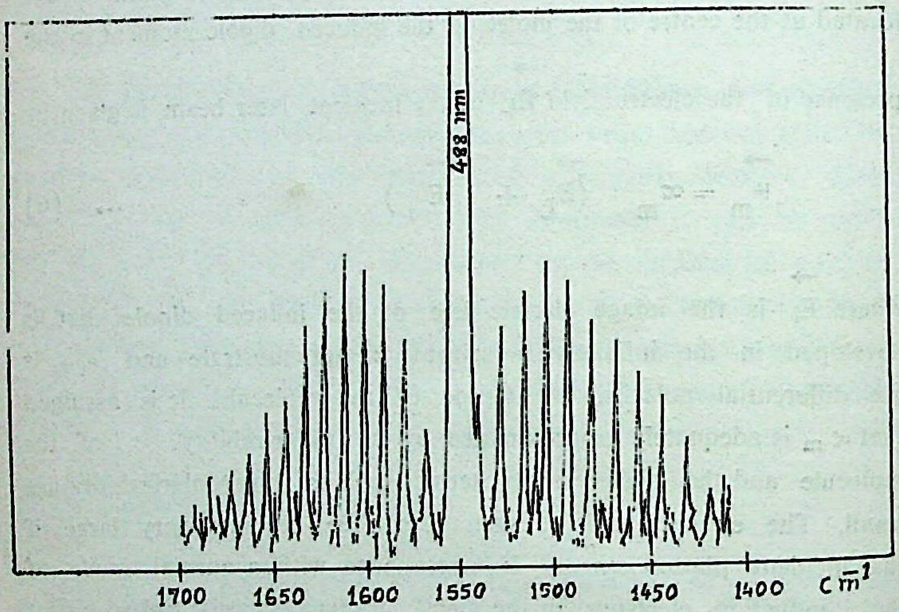
The free electrons in metals represent an extremely polarizable medium which can interact with and can be vibrationally modulated by an appropriately adsorbed molecule on the metal surface. The coupling between the conduction electrons and the adsorbate takes place through the image electric field generated in the metal by the adsorbate. If we assume the molecule to be crudely approximated as a point dipole located at the centre of the molecule the induced dipole moment in the presence of the electric field $\vec{E}_L$ of the incident laser beam is given by

$$\vec{\mu}_m = \alpha_m \quad (\vec{E}_L + \vec{E}_i) \qquad \ldots\ldots(6)$$

where $\vec{E}_i$ is the image electric field of the induced dipole that is developed in the infinitely polarizable metal substrate and α_m is the differential polarizability tensor of the molecule. It is assumed that α_m is adequately approximated by the polarizability α^0 of the molecule and the higher order terms such as hyperpolarizability are small. The electric field at such a surface becomes very large if the incident photon energy is in resonance with a normal mode of the conduction electrons in the metal. Raman intensity enhancement of several orders of magnitude is possible at physically obtainable separations between the surface and the adsorbate due to the image field enhancement mechanism.

Studies on Molecular Structure :

One of the most important applications of linear or spontaneous Raman effect has been the studies of molecular structure and molecular dynamics. The form of the molecular vibration can be studied by measurement of the depolarization ratio and thus definite assignments of vibrational frequencies to modes of vibrations can be made. The use of lasers in recording Raman spectra of gaseous, liquid and solid samples has revolutionised this branch of science due to the high intensity and high monochromaticity of these excitation sources. Samples which showed very weak Raman effect with ordinary monochromatic light sources like mercury arc can now be easily studied with lasers. The scope and power of lasers is best illustrated by recording the vibrational Raman spectrum of O_2 molecule in air without any sample cell. The laser radiation from an argon ion laser is focussed in air in front of the slit of the spectrometer and the



(Fig. 4 : Vibration-rotation Raman band of O_2 in air with 0.21 atom partial pressure excited with argon ion laser at 488 nm with a power of 500 milliwatts.)

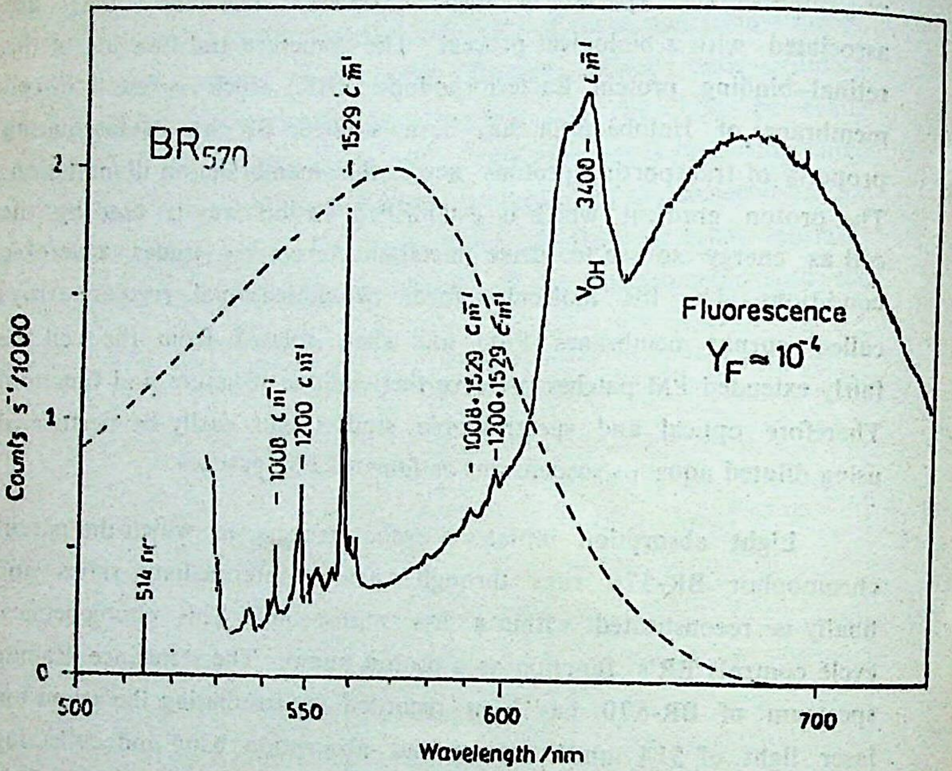
resulting spectrum is shown in Fig. 4. The rotational structure of the vibrational band is clearly resolved from which the internuclear separation between two oxygen nuclei in O_2 molecule can be easily calculated. The lasers used for linear Raman spectroscopy have powers of typically 50mW to 2W.

Studies on Biological Systems :

Raman scattering is an ideal tool for studying the formation of intermediate species in fast chemical reactions that are associated with a biological process. The structure and function of the retinal–binding protein, Bacteriorhodopsin (BR) which is found in cell membrane of Halobacteria has been studied. BR has a fascinating property of transporting protons across the membrane on illumination. The proton gradient which is established in this way is used by the cell as energy source to drive metabolic processes under anaerobic conditions. The BR molecules form two-dimensional regular arrays called purple membranes (PM) and when isolated from the cell the fairly extended PM patches preserve their unique structure and function. Therefore optical and spectroscopic studies can easily be performed using diluted aqueous suspensions or films of PM patches.

Light absorption initiates a cyclic process in which the parent chromophor BR-570 runs through various intermediate states and finally is reconstituted within a few milliseconds. This photochemical cycle controls BR's function as a proton pump. The resonance Raman spectrum of BR-570 has been recorded by irradiating the argon ion laser light of 514 nm into its broad absorption band and collecting the scattered radiation from 500nm to 700nm as shown in Fig. 5. Besides the sharp Raman bands which constitute the coherent signal, one observes a broad emission whose spectral distribution can be attributed to the non-resonant fluorescence of BR-570. The lifetime of the resonance state is estimated to be 1.4×10^{-14} second as compared to the time constant of 0.43×10^{-12} seconds for the primary photoreaction. Thus one arrives at the conclusion that probing of a photolabile BR chromophor by resonance Raman scattering is not perturbed by its primary photoreaction. The C=C stretching of the retinal moiety gives rise to the most intense band in the resonance Raman spectrum [$\nu=1529\text{cm}^{-1}$ in Fig. 5]. These bands not only differ in wavenumber but also in bandshape and width in going from BR-570 to the other intermediates in the photochemical process. This property of the

C=C stretching vibrations has been used as a diagnostic tool in kinetic measurements.

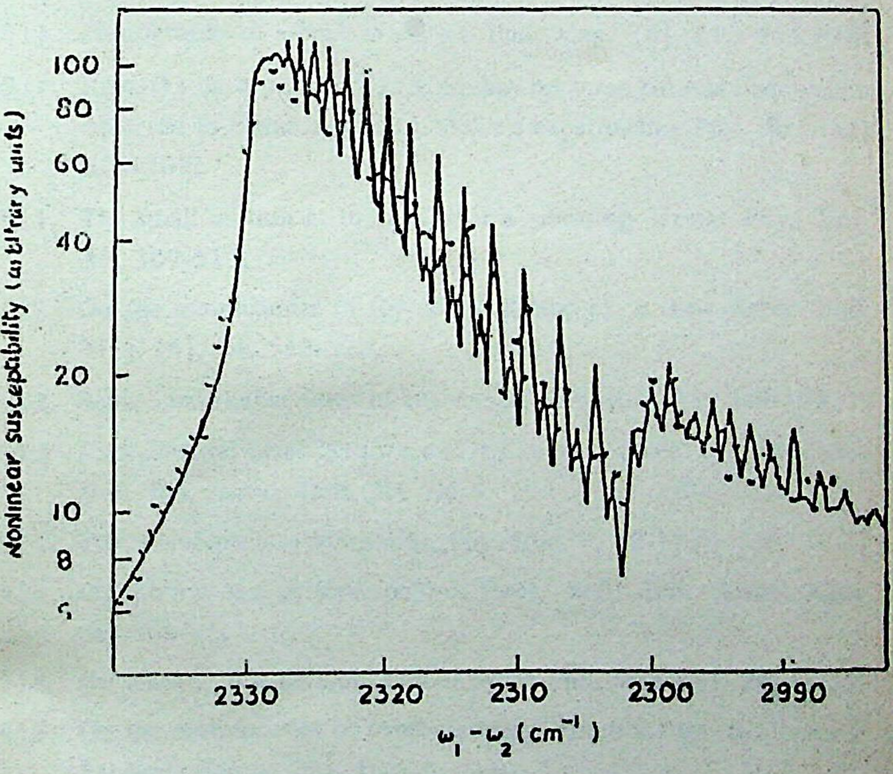


(Fig. 5 : The dotted line shows the absorption spectrum of BR-570. The sharp bands are due to resonance Raman scattering of BR-570 while the broad emission is due to fluorescence. The broad band at 3400 cm^{-1} originates from the water solvent.)

The mechanisms of photon absorption and detection by the visual pigment rhodopsin alongwith reaction dynamics of chlorophyll and the heme group have yielded a wealth of data through Raman spectroscopy. Recent applications of Raman spectroscopy to DNA probe the dynamics of the various helical forms of DNA and the transitions among them.

Applications to Combustion Diagnostics :

The availability of high peak power, pulsed lasers has made coherent anti Stokes Raman scattering (CARS) potentially attractive for nonintrusive, in situ measurements of species concentrations and temperature in combustion devices such as furnaces, gas turbine combustors and internal combustion engines. The superiority of CARS over incoherent spontaneous Raman scattering derives from its high signal conversion efficiency and the fact that the CARS signal emerges as a coherent laser like beam. Its coherent behaviour ensures collection of the entire signal rather than a small fraction as in an incoherent process. Furthermore the CARS is collected over such a small solid angle that collection of interferences is greatly minimised.



(Fig. 6 : CARS spectrum of N_2 in exhaust of engine,) The vibrational Raman shift of N_2 molecule has been extensively used to monitor the temperature in combustion processes. In these measurements a narrow band Stokes laser is scanned synchronously with the engine cycle to generate the CARS spectrum piecewise. The time averaged spectrum of N_2 thus recorded is shown in Fig. 6, where the dots represent the experimentally observed signals and the solid line represents a theoretically computed spectrum with a temperature of 1150 ± 50K and a N_2 concentration of 78 ± 5% in good agreement with thermocouple and gas chromatograph measurements giving 1050K and 78% respectively.

CHANDRASEKHARA VENKATA RAMAN

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Dr. Sir C. V. Raman's Address

B. H. U. Convocation-1929

"Being an Honorary Professor of the Benares Hindu University, I have to regard the invitation to address you this afternoon as a call of duty rather than as an honour. I might perhaps even say that the call comes as a rebuke for my having allowed nearly three years to elapse since my last visit to Benares. I will not however accuse myself by making excuses for this apparent remissness on my part. It is sufficient to remark that during a considerable part of this period, I have been, to use old-fashioned language, a peripatetic philosopher, or in more modern language a carpet-bag scientist who goes about, from place to place, lecturing here, there and everywhere, and seeing the world. My task as a traveller has not been altogether an unpleasant one. It has taken me far and wide. It has taken me twice across the American continent from the Atlantic to the Pacific and back, once through Canada and once through the United States. It has taken me through northern, western and southern Europe, and last of all it has taken me through mysterious Russia from the Baltic to the Caspian and back. In these travels it has been my privilege to come into contact with many men of science of the highest distinction, and discourse with them on problems of scientific research and education. It has been possible for me to visit the most renowned centres of scientific research and many Universities in the two continents. These have been of the most diverse types. Some of the Universities, I visited, as for instance, Upsala in Sweden, are hoary with age, others as for instance, Chicago, are of more recent origin but might well be described as youthful giants; some Universities as for instance, those in Western Canada are the creation of the State and are run entirely by the money of the tax-payer, while others again, as for instance, Stanford University in California are the result of the philanthropy of a single man and enshrine his love of learning. As I said just now, these travels have taken me far and wide, and now I find myself once more amidst you. But, ladies and gentlemen, I need hardly assure you, that while far from Benares, in distant lands, among strangers, I was never far from Benares in thought and mind.

Many a time when travelling in America, I was called upon to speak of India's ancient civilization and of her new renaissance. They were anxious to hear of our country. When I accepted such invitations, I had to unfold a picture of our people, to paint in words India as she was and as she is to-day. Do you think I spoke of Madras or of Calcutta ? No ! I spoke of Kashi, of Benares, of the historic city on the ridge overlooking the Ganges which stands as the very heart of India, as the living centre of our ancient culture and learning. I spoke of the new University which has sprung up, so fitly, at this age-old seat of learning and is the living embodiment of the aspirations of new India. That was the message I gave to America. Coming back now here and looking round, the question naturally arises to one's mind how does our University stand to-day ? I confess my feelings are a mixture of pleasure and pain. I am filled with pleasure at seeing the remarkable growth of the University, of the strides it has made forward, and is making towards the realisation of those great and practical ideals which your Vice-Chancellor has in view. I am pained because even his devotion, even his self sacrifice and earnest labour have not completed yet the task of building up that University as he and you and I all wish to see.

You may perhaps ask me what lessons have these travels brought home to me, what message have I to give you this afternoon ? You have just heard the exhortation from the lips of your Vice-Chancellor addressed to your graduates to think, speak, and act the truth. Standing here, I cannot but follow his injunction. Let us first look at the bright side of the picture. Many of the universities I visited are great centres of scholarship; some of them are of great age; others have the advantage of an exceptionally favourable natural situation; some again are extremely well-equipped for research; others are very richly endowed, and so on. Having seen them, I can say that the Benares Hindu University has no reason to feel ashamed of itself or to fear comparison with them. When saying this, I am referring, not to all the advantages mentioned, but to the one thing most vital to a University, that is the breadth and strength of the ideals which animate its activities. In this respect, we have nothing to be ashamed of.

But there is another side to the picture. The growth of our University has been phenomenal. The Princes and peoples of India have been generous in responding to the call when the needs of the University were urged by the Vice-Chancellor. But much remains to be done in order that the future of the University as a centre of learning may be fully assured. To mention only one very important matter, we require a dozen University Professors to be fully endowed, one in each major branch of knowledge. Such endowments would enable the services of the most eminent teachers in India to be obtained and retained for the University, and by stabilising the finances of the University enable its work to be carried on under conditions satisfactory to the teacher and the taught alike. I can imagine no worthier manner in which a donor's name can be associated with the University than by the creation of such endowed chairs. What more can I do than add my feeble voice to the voice of your Vice-Chancellor in appealing to all patrons of learning in India to come forward and generously support the work of the University ?

"Sir, I have been asked by you to address the Convocation. May I remind you that the Convocation includes the Vice-Chancellor, and venture therefore to address you particularly ? I hope you will not take it amiss We in all parts of India—I am now talking as a Calcutta man—have followed with great admiration the success you have so far achieved in building up this University. We regard you as one of the greatest of those who have helped to make India what she is to-day. Sir, you have rendered conspicuous service to India in many different capacities. This is not the time or the place to speak on all that you have done in these capacities. But I may venture to tell you that there is nothing for which you are responsible which is more remarkable than the creation of this great centre of learning. It stands as a unique achievement which entitles you to a very special place in our esteem and gratitude. I now appeal to you, Sir, with all the force that I can command, that you should put every other task aside and devote yourself wholly to the carrying out that work forward to completion and making that great vision which inspired your labours an accomplished fact in all respects. In saying this, may I venture to remark that there are others, younger than you, who have the strength to guide the destinies of India in the other fields of your activity and can be trusted to shoulder those burdens. But there is none, if I may venture to say so, other than yourself who can undertake this task of making the Benares Hindu University what it ought to be. Sir, in giving praise where praise is due, one should also have the courage to criticize where necessary, though, in order to be useful, such criticism should be constructive. If in the course of my address this afternoon I have occasionally to use forcible language, pray do not for a moment imagine that I am guilty of any feeling of disrespect to our people or our institutions.

I cannot address you in a better way than by telling you a story of my visit to England in the year 1921. I went to Cambridge and met by appointment Sir Ernest Rutherford the great Cambridge Physicist-whose name is honoured wherever science is studied. He received me with great cordiality and showed me over the Cavendish Laboratory. We then walked home to his house through the streets of Cambridge. It was a bright sunny day and a great many students were, playing in the College grounds. I remarked to Sir Ernest, a little mischievously,–"It seems to me Cambridge is a place for play and not for study". Sir Ernest turned round and said : "We do not try to grow bookworms here. We train men who can govern an Empire". That was his spirited reply, which I shall not easily forget. Those words may well be the motto of a University. It is not the function of a University to grow bookworms. The function of a University is to train men to serve their country and above all to train those who can become leaders, leaders of Science, leaders of Industry, leaders in all other fields of activity.

Let us be frank and ask ourselves "Are the Universities in India merely nurseries for book-worms, or are they really trying to train men for the highest functions which they may be called upon to perform ?"

Before answering this question, let me tell you another story, this time from the Pacific Coast in California. I was invited by R. A. Millikan, the great American physicist, not merely to visit his laboratory at Pasadena but also to accept an appointment on the Professorial staff of the California Institute of Technology for a whole term. I may mention that the physical laboratory attached to this institute is the foremost of all such laboratories in the United States. I accepted the invitation and lived in the club attached to the Institute and lectured every day in the same way as other members of its staff. I had thus an opportunity, such as rarely comes to a casual visitor, to come in direct touch with the true American temperament, life and outlook. I was profoundly impressed during my stay at Pasadena with the attention paid to the military training of the students, and the results of such training. Rarely a day passed in which I did not see in the campus of the Institute at all hours, groups of students marching, drilling, learning to shoot and perform the duties of a soldier. Indeed, it might have seemed that the students were training to become professional soldiers, and not, as in reality they were, electrical engineers. The conviction was borne in upon me be actual contact with the students of that Institute that nothing helps a young man to acquire physical stamina, descipline and a right outlook on life so much as military training. I regard military training as an essential part of any scheme of education in a University. Nothing is more necessary at the present day than the introduction of compulsory military training of an intensive type for every student in our Indian Universities. I have no doubt that if this is done, the experiment would prove an absolute success and do more to build up the character and strength of the rising generation than the study of a whole library of books. Pray do not imagine however, that I consider the function of a University to be the training of soldiers I advocate military training purely as an educational measure bearing in mind its benefit to the individual on the physical side, for without a solid foundation of physical strength and stamina, no strenuous activity of any kind is possible. I have no doubt myself, however, that if all soldiers were University men thus trained, they would be just good soldiers and we should hear less of the brutalities and horrors of war.

On the intellectual side, the development of the faculties by use and not the mere acquisition of knowledge should be in the forefront as the object of education. This distinction is most vital and its importance is greatest when we reach the University stage of education, Speaking of it. I am reminded of another great Indian who is no longer with us but who did wonderful work in advancing the intellectual outlook of our Indian Universities. I am referring to the late Sir Asutosh Mookerjee. He realised that the function of a University is not merely to train students to be bookworms. In case you do not realise what I mean, I will ask you to remember that a bookworm consumes books but produces only dust. A true scholar does not merely consume knowledge but also produces knowledge. He does not merely absorb but also radiates. Sir Asutosh understood this and set before himself as his life-work the task of creating an organisation that would teach men to become radiators and producers of knowledge. His great work has not perished. But there is a danger that the new spirit which he tried to infuse into our Universities may die for lack of nourishment. Our Universities are so engrossed today with the task of conducting examinations and with innumerable meetings of Boards and Faculties, Courts and Councils, Senates and Syndicates that they have no time or energy left to perform the highest function of a University which is to stimulate intellectual activity and advance knowledge. There is a danger today of its being forgotten that examinations and Faculty meetings are only means to an end not an end in themselves. There is a danger to-day of the production and advancement of knowledge receding into the back-ground in the intellectual outlook of our Universities, of their being regarded as something beautiful and great, like the white snow in the top of the Himalayas, to be admired from a distance but not to be grasped or touched. I think this idea prevails today not only amongst those outside academic circles but also amongst some of those who claim to control our Universities and ought to know better.

Let me remind you that we live today not in the age of the Vedas and the Upanishads, we live in a modern age, we live in an age of research, a period of intense striving to create new realms of thought, to penetrate the mystery of Nature by the use of all intellectual and material forces under human command. During the last hundred years vast fields of new knowledge have been discovered and cultivated, and everything points to an increasingly vigorous advance into regions as yet unknown. We in India as a people cannot afford merely to stand by and be passive spectators of this remarkable outburst of human activity. To stand aside would be to confess ourselves an effete and worn out people, fit only to be laid on the shelf and suffer economic and political extinction.

Though this is an important consideration, yet it is not the only one to be taken into account, I ask you to look at research from another standpoint. What is research ? It is the seeking after knowledge, and must therefore be of the most fundamental significance in all schemes of education. You must remember that knowledge at the present day is not a dead knowledge enshrined in books but a living and growing knowledge with which we are all concerned. Can you imagine for a moment that living knowledge can be procured, can be obtained merely by the study of books, by turning your teachers and students into bookworms ? No. Your teachers and your students have to take part in that stream of human activity which I have referred to. A University is not a University if this is not understood, if this is not daily practised. A University is not a University but only a high school if the advancement of knowledge is not continually kept in sight as a duty of teachers and students alike. It is in the attempt to discover new facts or new relations between known facts, which we call research, that a true insight into a new and growing body of knowledge is obtained, You must be one of the seekers, or else you will get left behind. There can be no sitting on the fence. You must be in it or out of it. You cannot tell the depth of the river or learn to swim in it by standing on the bank and watching it flow by, but must pluck up courage and plunge into it. So long as our teachers and our students are not inspired in their daily work by such ideals, so long as it is not research but administration that dominates the outlook of our Universities, we can hope for no great advance either in the intellectual output of India or the quality of the work done in our centres of learning. The encouragement and development of research forms one of the most urgent problems facing us today in India.

What is necessary now is an awakening and a realisation of the immense importance and urgency of the problem and the creation of a new outlook in our Universities. We must mobilize the human and material resources available for the development of research in India. To pay mere lip-service to the importance of research is of no use. We have to devise practical measures by which it can be made an essential part of the work of our Universities.

The record of intellectual activity in India during the past fifty years, depressingly small though it be, yet shows some signs of hope for the future, some indications of the dawn of a new era. Looking back over the period, perhaps the brightest ray of light that meets our eye is the remarkable, though to our sorrow, all too brief a career of the late Mr. Ramanujan. His work bears the unmistakable stamp of genius, and in its quality is not unworthy of being set side by side with that of the greatest mathematicians of Europe. Any practical scheme for the development of research in India must be based on a knowledge of the facts concerning research known by experience of the last century. The human factor in research dominates all others. The case of Mr. Ramanujan is one illustration of the striking fact revealed by the study of the careers of scientific men during the past century concerning the relation between the age of a man and the character of his scientific work. A very remarkable proportion of all strikingly original work has been done by comparatively young men. The reason for this is not far to seek. It is the young man, receptive and enthusiastic, who brings to bear on the problems of science a fresh outlook and ventures to enter with courage and energy, fields where the caution of the older worker may draw him back. Speaking broadly, it may be said that a man's most brilliant ideas come to him when he is young, say between the age of twenty-five and thirty-five, The later period, up to say middle age is largely taken up with following the trail blazed out in the earlier years and the work done in it makes up by maturity of judgment resulting from wider experience anything that it may lack in brilliancy or originalty. Even at middle age, however, exceptional individuals with a favourable environment, may show great intellectual power and brilliancy. Sooner or later, however, age begins to tell and with the weakening of the receptive faculty so essential to the investigator, the power to make significant contributions to knowledge wanes. Experience teaches that men of sixty often make admirable statesmen and administrators. But they hardly count as leaders of scientific research. At that age, there is only one thing for a University Professor to do, and that is to retire with honour from his chair and become a Vice-Chancellor.

Science then teaches us the gospel of youth. Rightly viewed one sees here a great encouragement to our young men fresh from our Universities to exert themselves and to exercise their intellectual gifts while yet there is time and before they grow rusty from disuse, These facts have also an obvious lesson for our publicists and others who control the funds available for research. To be really productive money should be spent in providing opportunities for the work of men who are comparatively young or else are yet in the prime of life and have given proof of possesing originality and power to initiate new lines of advance. Any well-thought out scheme for the promotion of research in India would include the provision of National Research Fellowships on an extensive scale for young men between the ages of twenty-five and thirty-five who have given proof in their University career of real originality and power to do independent work. Such fellowships would enable young men, who would otherwise drift to some kind of routine employment, to devote themselves to research during the best years of their lives. They would form the nucleus from which could be recruited the Professoriate of our Colleges and Universities and the technical staff required for the development of manufacture and industry.

I can hardly think of any better way in which money can be spent today in India than by the payment of scholarships and fellowships to highly-qualified young men capable of doing independent original work, and the payment of money actually required for the equipment of research laboratories and research libraries. Money spent on these objects will sooner or later repay itself manifold. The promotion of research should be an urgent and insistent claim both on the generosity of private donors, and on the liberality of those responsible for the administration of public funds in India. At the same time, it is well to urge that the utmost discrimination should be exercised in the award of such financial assistance. Particularly with regard to the expenditure of public money it is necessary to prescribe such safeguards as would ensure the available funds being distributed in the most economic manner so as to secure the maximum of results.

It would be well to form an Advisory Council for Research in India composed of scientific men both official and non-official, whose advice would be sought with regard to the distribution of grants to individuals or institutions Such a Council may be trusted not to overlook the claims of the capable but comparatively less known workers whose work may be of equal scientific importance but, unlike that of the better-known men, is hampered by want of even the slenderest resources. It should also be laid down, as a general principle that whenever State aid is given for research to an institution, it should be made the first condition that fully audited accounts of such an institution are published, and that the fullest details are furnished in the accounts of how the grants given are expended. Failing such stringent audit control, there is a great danger that funds allocated for research are not expended on the purposes for which they are granted and are thus diverted from channels in which they can be more profitably utilized.

I would urge on patrons of learning throughout India that they should found in connection with the Benares Hindu University, suitable research fellowships in different branches of science. Such fellowships would be a great accession of strength to the academic work of the University and enable Benares in due course of time to take rank with the leading Universities of the world.

Something can be done by our Indian Universities for the promotion of research even with the existing resources. In my opinion no person should be appointed to teach science to College classes who has not spent at least two years in an approved research laboratory studying modern developments and presented a thesis embodying the results of such study. Such teachers as already hold College appointments and have not had experience of modern developments in research should be encouraged to take study leave for a year and deputed to work under some eminent specialist or other. Such men when they return to their College should be encouraged to continue their work in a selected field of research and thus to remain in touch with the living spirit of science. It is a mistake to imagine that research cannot be carried on except with resources and materials altogether beyond the financial resources of an ordinary College. Much can be done even with modest resources by men who have obtained the necessary knowledge and skill by working in the more highly organized laboratories. A little assistance given to such men in aid of their work will often go a very long way.

The ethics of scientific research is a matter on which but little has been said or written in India. This subject has many phases some of which are of vital importance. One aspect of the ethics of research touches upon the relations between a professor and his students or assistants. It is fatally easy for a scientific man who has reached eminence to reduce the workers in his laboratory to a position of complete intellectual subordination and in fact to turn them into mere mechaical assistants. Much depends on the type of workers chosen. Unless they are youngmen of real brilliance and independence of mind and are allowed the greatest freedom in the exercise of initiative, the degeneration of so-called research scholars into routine assistants is almost automatic. Scientific men are not unknown who in choosing "scholars" regard independence and originality as disqualifications. Such men do not found schools. Usually however when both professor and student are men of high calibre, the relations between them are of the happiest and are beneficial to both.

Another important aspect of the ethics of research is the attitude of the man of science towards the results if any of his work. Research is best carried on for its own sake. Indeed the history of science teaches us that research may confer benefits of the highest importance on the human race, as witness the work of a Faraday or of a Pasteur, and that such benefits often accrue when they are not specially sought for. There is nothing sordid however in the investigation of Nature directly with a view to harness her forces for practical benefit. I would warn my young friends very specially against regarding research as a pathway to self-glorification advertisement and self. Self-advertisement, for whatever reason it may be pursued soon becomes an end in itself. and its results are most evil when seemingly it is most successful. The man of science who habitually indulges in it soon comes to believe in his own perfection and infallibility and loses that clearness of vision and power of rigid self-criticism essential to an investigator. Self-praise is scientific suicide.

There are other aspects of the subject on which I could speak. I must remember, however, that your patience is not unlimited, and will therefore conclude my address with a few words regarding the Benares Hindu University. I see in this University which seeks to bring together our ancient culture and the knowledge of the new age, a great instrument for the uplifting of our country and for cementing together the people of India into a single nation. I see in it a centre of learning with the greatest potentialities for the intellectual, moral and material welfare of our countrymen. I would urge on you, graduates, to remember with pride that you are the alumni of a University which is truly a National University of India, a University in which students and teachers from all parts of India learn to live and work together. I would urge you, Sir, and every one present here, not to rest, until you have done your utmost to make our Benares the greatest and most truly Imperial University in India, a centre of culture such as we should all justly feel proud of, to make it what you and I and every one else would wish it to be. I recall with pleasure and pride that what is now the University with its magnificient colleges, hostels and residences and with its avenues and roads was, not many years ago, just open fields. Much has been done. But much still remains to be done. I earnestly appeal to the Princes and people of India, to the Imperial and Provincial Governments to be generous to an Institution which can justly claim to be the most outstanding effort of educational idealism in the modern history of India, and to help to make it worthy of the Indian people.

श्रीरमणशतकम्

डा० शिवदत्तशर्मा चतुर्वेदः

सी. वी. रमणं मन्ये भारतभाग्यस्य सत्कारम् ।
शुभ्रैर्यशोवितानैर्भूषितकायं विगतमायम् ॥१॥

वैज्ञानिकसंसारे भारतवर्षस्य मस्तकं तेन ।
सर्वोन्नतं विदधता किं किं नासादितं तत्त्वम् ॥२॥

नववैज्ञानिकविश्वे चूड़ामणितां दधानोऽसौ ।
सी. वी. रमणो देशे देशे सर्वत्र वन्दनीयोऽभूत ॥३॥

श्रीचन्द्रशेखरोऽसौ वेंकटरमणः स्वजन्मसंसिद्ध्यै ।
प्रकृतिपरीक्षणविद्यासमर्पितः समभवन्नूनम् ॥४॥

ऋषिरेवाऽयं कश्चित् साक्षात्कृतवान्स्वयं धर्मम् ।
रमणप्रभावसंज्ञा संजाता तस्य धर्मस्य ॥५॥

धर्माणि यानि प्रथमान्यासन्मन्त्रेषु कथितानि ।
यन्त्राधारेण पुनर्दर्शनमेषां हि विज्ञानम् ॥६॥

एवं साक्षात्कारे धर्माणां जायते काचित् ।
नव्याविष्काराणां विभूतिदीप्तिः परा लोके ॥७॥

जनजनमध्ये तेषां लाभा ये वा वितीर्यन्ते ।
जीवनमेतन्निखिलं प्रपूर्तयेऽग्रेसरीभवति ॥८॥

श्रीचन्द्रशेखररमणमहाशयेनाथ जीवने स्वीये ।
क्षणशः क्षणशः कृत्वा नूनं तप्तं तपो घोरम् ॥९॥

इदमेव तदृषित्वं यस्मिन् सन्तप्यत तपो नित्यम् ।
तादृशतपसः फलमपि जनतासामर्थ्यवृद्धिर्हि ॥१०॥

केवलमेका लक्ष्ये दृष्टिस्तेषां वरेण्यानाम् ।
अन्यत्किञ्चित् सर्वं तेषां नास्त्येव नास्त्येव ॥११॥

सर्वे जनाः शयाना यस्यां तिष्ठन्ति सा रात्रिः ।
तेन परीक्षणकार्ये क्षणशः क्षणशोऽथ जाग्रता नीता ॥१२॥

यद्यपि भारतवर्षे विज्ञानानां विभूतिरूपाणाम् ।
पूर्णः प्रकर्ष आसीज्जगद्गुरुत्वं तथाऽऽदिमे काले ॥१३॥

योऽयं यज्ञः कश्चित्ज्जनकोऽभूत्सोऽथ विद्यानाम् ।
नूतनगवेषणानां तत्राऽऽजायत परा दीप्तिः ॥१४॥

सिद्धान्ताऽऽविष्कारे प्रयोगशाला च यज्ञशालाऽऽसीत् ।
मन्त्राक्षरेषु सर्वा संगतिरासीत् प्रयोगाणाम् ॥१५॥

विश्वामित्रमहर्षिर्नानानव्यप्रयोगाणाम् ।
संस्कर्ता समजायत चकितोऽभूद्यत्र संसारः ॥१६।

सर्वाऽप्येषा सृष्टिर्ब्रह्मादिस्तम्बपर्यन्ता ।
विश्वामित्रेण पुनर्निर्मितिमार्गे समानीता ॥१७।

नो विश्वासं कुरुते लोकोऽद्यत्वे तु गाथासु ।
घोरतपश्चर्यायाः फले कथं श्रद्दधेल्लोकः ॥१८॥

यद्यद्वा फलमासीत्तस्मिन् काले तु विद्यानाम् ।
जात्यादिभिर्विशिष्टैरधिकारस्तत्र तत्र कृतः ॥१९॥

किन्त्वाश्चर्यमयाणां यन्त्राणामद्य सद्भावे ।
सर्वाऽप्येषा जनता फलैस्तु लाभान्विता जाता ॥२०॥

जगदीचन्द्रवसुना संसारे नूतनोन्मेषः ।
प्रादुर्भावित आसीद् वृक्षे चैतन्यसाधनारूपः ॥२१॥

रामानुजमितिनाम्ना विख्यातेनाऽथ विद्वरेण्येन ।
गणितीये विज्ञाने प्रकाशपातः कृतो नव्यः ॥२२॥

सी. वी. रमणेन तथा चमत्कृतो निखिलसंसारः ।
सूर्यकिरणविज्ञानं नूतनमाभापता नूनम् ॥२३॥

नार्लीकरो नितान्तं निपुणः सापेक्षतावादे ।
आईन्स्टीनमहाशयसिद्धान्तं विशदयति नित्यम् ॥२४॥

भाभामहोदयानां विज्ञानानां परा सम्पत् ।
पूर्णं जगन्नितान्तं विद्योतयते स्म नव्यया दीप्त्या ॥२५॥

नव्याऽविष्काराणां विज्ञानेषु प्रदीप्तानाम् ।
या शीघ्रताऽस्ति सम्प्रति विस्मरणं जायते तत्र ॥२६॥

एकोऽस्त्याविष्कारो यः केनाऽपि कृतोऽद्यत्वे ।
अन्येन केनचित्त्वथ तत्खण्डनमपि कृतं तूर्णम् ॥२७॥

इत्येवं नानाविधविज्ञानाविष्कृतीनां वा ।
नित्यं ताण्डवलीला विलोक्यते ज्ञानसाम्राज्ये ॥२८॥

प्राचीनाः सिद्धान्ता नव्यैर्नित्यं विलोप्यन्ते ।
नव्यतमैरथ नित्यं ते नव्या अपि विलोप्यन्ते ॥२९॥

किन्तु रमणसिद्धान्तस्तथाविधोह्यचल एवाऽऽस्ते ।
विज्ञानविश्वमध्ये सूर्यचन्द्रायितं तेन ॥३०॥

प्रथमः प्रधानमन्त्री जवाहरो यः स्वदेशस्य ।
वारं वारं गत्वा रमणं वर्धापयामास ॥३१॥

आविष्कारः सोऽयं विज्ञाने स्थायितत्त्वं तत् ।
संस्थापयिष्यतीति दृढ़ा रमणे बुद्धिः प्रतिष्ठिता ह्यासीत् ॥३२॥

रमणाऽविष्कारस्य च तन्नाम्नैवाऽथ घोषिता संज्ञा ।
रमणप्रभाव इति या सर्वैर्वैज्ञानिकैर्नितराम् ॥३३॥

निखिलेऽपि च भूवलये वैज्ञानिकमध्य एवेयम् ।
रमणप्रभावभाषा नितरां संमानिता जाता ॥३४॥

संसारस्य श्रेष्ठो योऽसौ नोबुलपुरस्कारः ।
सोत्यादरान्निकामं प्राऽदीयत चन्द्रशेखरायाऽस्मै ।।३५।।

शुभ्रपुरस्कारं तं सम्प्राप्याभाषमाणेन ।
स्वीयेऽस्मिन् सिद्धान्ते विज्ञानस्यायतिर्दृष्टा ।।३६।।

आरोपण-संरोपण-विकीर्णनादि प्रकाशकिरणानाम् ।
भूभौतिकं रसायनमित्येतत्सत्यमुपकुरुते ।।३७।।

प्रायोगिकस्वरूपे सारल्यं चात्र सिद्धान्ते ।
स्पैक्ट्रम तत्त्वाऽवाप्तौ सहजत्वं प्रेरणा भूमिः ।।३८।।

यदवधि सिद्धान्तोऽयं परीक्षणान्निश्चितो जातः ।
तस्मात्कालात् सर्वे सारल्येन स्थिताः सन्तः ।।३९।।

आचामन्ति तमेतं सिद्धान्तं ते गवेषकाः सर्वे ।
वैज्ञानिकाः प्रथमतस्तदुत्तरं वा गवेषणं तेषाम् ।।४०।।

स्वीयोदात्तविचारप्रकटनवेलासु नित्यसंदीप्तः ।
सी. वी. रमणो जनताकल्याणे चेतनो ह्यासीत् ।।४१।।

विज्ञानाऽविष्कारे विनाशरूपं यदेतदप्यास्ते ।
तत्प्रतिपक्षे स्वीयान्भावान्संयोजयामास ।।४२।।

साधनगता सरलता सौकर्यं शक्तिशालित्वम् ।
प्रददाति तेन कार्येषून्नतिरासाद्यते काचित् ।।४३।।

एकस्मिन्नपि कार्ये संजाते साधनाऽभावे ।
समयश्रमधननाशेनौदासीन्यं समायाति ।।४४।।

यस्मिन् यस्मिन् काले साधनसम्पन्नता चाऽसीत् ।
इतिहासपृष्ठानां विभूतिरूपः स एव कालेऽभूत् ।।४५।।

साधनसमर्पकाणामेतावान् विद्यते महिमा ।
पुरुषार्थानां काचिद् विलासलीला विलोक्यते तत्र ।।४६।।

क्षणवत्संपूर्णोऽयं कालो यात्येव कार्यशीलानाम् ।
प्रकृतिपरीक्षणकार्ये लग्नानामात्मलीनानाम् ।।४७।।

जीवनपद्धतिरेषामन्येषां प्रेरणा भूमिः ।
एकोऽपि महापुरुषो वा कोटिसमुद्धारको भवति ।।४८।।

आयतिदीप्तिकरोऽसौ लोके सर्वत्र नन्दितो भवति ।
नैकानां च युगानामनन्तरं लभ्यते सुमहान् ।।४९।।

श्रीचन्द्रशेखरोऽसौ वेंकटरमणस्तथा विधो जातः ।
येनादृता निकामं काचिल्लोकोत्तरा सरणिः ।।५०।।

तस्यैतस्याद्यत्वे शुभ्रयशोभिः प्रदीप्तस्य ।
शतवार्षिकी नमस्या विधीयते काऽपि राष्ट्रेण ।।५१।।

नेदं केवलमेकं पारम्परिकं कृतज्ञतामात्रम् ।
संमानोऽयं स्वीयस्यैव चरित्रस्य विज्ञेयः ।।५२।।

सी. वी. रमणो नैकः सा संस्था कार्यशीलानाम् ।
काऽपि भविष्यत्सरणिर्देशे वैज्ञानिकानां सा ।।५३।।

यद्यपि सर्वा शिक्षा बुद्ध्युत्कर्षप्रदायिका भवति ।
जीवनमुन्नेतुं किल काम्या विज्ञानशिक्षैव ।।५४।।

रमणप्रभावनाम्ना नैकं तत्त्वं समुल्लसति ।
किन्त्वेकं परिशीलितमेतद्दर्शनमहो जातम् ।।५५।।

पश्यन्तः शृण्वन्तः प्रकोष्ठमध्येऽखिलं विश्वम् ।
सर्वेऽपि जना धन्या जाता विज्ञानसामर्थ्यात् ।।५६।।

लोकान्तरगतजीवनसंचाराणां गवेषणायां सा ।
काचिद्दीप्तिर्लब्धा पुष्टो येनाद्य संसारः ।।५७।।

जीवनमध्येऽद्यत्वे न विद्यते तादृशी धारा ।
वैज्ञानिका वरेण्या यत्र गवेषणपराङ्मुखा वा स्युः ।।५८।।

भारतवर्षे तावत्पुरातनादेव कालात्सा ।
सुप्रचलिता समासीत्काचिद्वैज्ञानिकी धारा ॥५९॥

संसारे प्राचीने सुवाङ्मये चाथ वेदानाम् ।
सर्वपुरातनतेयं विख्याता सर्वसम्मता चाऽस्ते ॥६०॥

वैदिकवाङ्मयमध्ये गवेषणायां प्रजातायाम् ।
विज्ञानस्यात्युच्चाः सिद्धान्तास्तत्र सम्मिलन्त्येव ॥६१॥

ते चाऽपि तु सिद्धान्तास्तत्रैवाद्याथ दृष्टिपथगाः स्युः ।
नो तादृषयन्त्राणां विवरणमत्रोपलब्धं स्यात् ॥६२॥

तेष्वेतेषु परीक्षणपरिपाटीसंस्थितेषु वेदेषु ।
चकितचकितभावोऽसौ विलोक्यते निखिलसंसारः ॥६३॥

ह्रासविकासविचारे पाश्चात्या ये तु विद्वांसः ।
ते सर्वदा विकासे विश्वासं साधयाञ्चक्रुः ॥६४॥

संसारोऽयं विकसति नाना रूपेषु दिव्येषु ।
पूर्वं यस्य तु नासीन्नामाप्यद्यैव तज्जातम् ॥६५॥

पूर्वमभावो येषां ते नूनं भावतां याताः ।
नाना नवाः पदार्थाः सैषा सरणिः प्रजायतेऽग्रेऽपि ॥६६॥

ये तावत्तु विचाराः पूर्वं नो दृष्टिपथयाताः ।
क्रमशस्तेऽथ विलासान् स्वीयान् सम्यक् प्रकाशयन्त्येव ॥६७॥

इत्येतादृशधारा विकासवादाऽनुकारिणी भाषा ।
प्रवहतितरां नितान्तं पाश्चात्यैः सम्प्रवर्तिता नूनम् ॥६८॥

भारतवर्षे तावत्पुरातनादेव कालात्सा ।
ह्रासाऽधारितधारा प्रवर्तिता वर्णिता चाऽस्ते ॥६९॥

सत्ययुगे यद्विकसितरूपं दृष्टं चरित्राणाम् ।
त्रेतायां तन्नासीद् द्वापरकाले ततोऽपि तत्क्षीणम् ॥७०॥

कलियुगकालेऽद्यत्वे ह्रासस्यैवाऽस्ति साम्राज्यम् ।
सर्वाऽप्युन्नतिधारा विलोपितैवाऽद्य कालेऽस्मिन् ॥७१॥

योऽयं विकासवादः स्तस्मिन्नूनं प्रवृत्तिमुपयाते ।
कीदृश्यप्यभ्युन्नतिरेषा नो दर्शनीया प्राक् ॥७२॥

या ह्रासवादधारा तस्यामङ्गीकृतायां तु ।
सर्वाप्यत्युच्चोच्चा समुन्नतिस्सा पुरैवाऽसीत् ॥७३॥

तेनैव प्राचीने वेदे सरणिर्विचाराणाम् ।
व्याख्यातॄणां भेदो महानयं दृश्यते तत्र ॥७४॥

पाश्चात्यानां विदुषां विचारमध्ये तु वेदानाम् ।
केवलपुरातनत्वं महत्त्वमूलं न तत्र विज्ञानम् ॥७५॥

ते द्रष्टुं प्रयतन्ते प्रदर्शिते खण्डयन्ति तत्सर्वम् ।
मूले एव विरोधस्तस्मिन्काले विकासानाम् ॥७६॥

या भारतीयसरणिस्तस्यां ह्रासोऽथ सर्वस्मिन् ।
आयति काले जातः सर्वादौ सा समुन्नतिः सर्वा ॥७७॥

तेनैव वेदमध्ये सर्वं ज्ञानं तथा च विज्ञानम् ।
क्रमशोऽथ सर्वंशो वा विलोक्यते सूत्ररूपेण ॥७८॥

न केवलं सिद्धान्ता अपितूदाहरणविपुलत्वम् ।
नाना कथाप्रवाहे सहस्रशोवा निभाल्यते सर्वैः ॥७९॥

सिद्धान्तोदाहरणे तत्त्वे द्वे सत्यतायां वा ।
नूनं प्रमाणभूते लोपे कस्यापि जल्पनं तत्स्यात् ॥८०॥

ये नूनं सिद्धान्ताः कथिता वेदादिशास्त्रेषु ।
प्रायोगिकं स्वरूपं कथासु तेषां समुल्लसति ॥८१॥

जाता एव युगेऽस्मिन्नाचार्यश्चाथ विद्वांसः ।
यैराविष्कृतमेतद्वेदेष्वेतेषु विज्ञानम् ॥८२॥

सायणसरणिर्याऽसौ व्याख्यायाश्चास्ति वेदानाम् ।
यज्ञाधारितकाया सा सरणिर्विश्वरूपाऽस्ते ॥८३॥

स्वामिदयानन्देन तु किमपि नवीनं पराक्रान्तम् ।
श्रीविद्यावाचस्पति मधुसूदनदर्शितं नव्यम् ॥८४॥

श्रीभारतीयतीर्थैः श्रीमद्भिः शंकराचार्यैः ।
गणिताख्यं विज्ञानं वेदे संसाधितं निखिलम् ॥८५॥

स्वामिविशुद्धानन्दैः सन्दृष्टं सूर्यविज्ञानम् ।
प्रत्यक्षं सन्दर्शित मासील्लोकस्य विस्मयस्तत्र ॥८६॥

एवमियं या सरणिर्भारतगौरवमुखेन संजाता ।
चकिता तयाऽथ नूनं वैज्ञानिकभूधराश्चाऽपि ॥८७॥

सी० वी० रमणसदृक्षैर्गवेषकैरद्य तत्रापि ।
नव्ये गवेषणाया मार्गे गौरवमथाऽऽज्ञप्तम् ॥८८॥

यद्यपि निखिलेऽप्यस्मिन् संसारे लक्षशो लग्नाः ।
वैज्ञानिके गवेषणमार्गे नव्याश्च विद्वांसः ॥८९॥

सर्वेषामपि तेषां यन्त्राणां वा विशालानाम् ।
योगो भवति नितान्तं मानवजीवनसमुन्नयने ॥९०॥

सी० वी० रमणेन पुनर्ये सुविचाराः प्रकाशिता आसन् ।
वैज्ञानिकसरणीनां मार्गे नूनं प्रवर्तमानेभ्यः ॥
ते देशगौरवं वा नूनं प्रस्फोटयन्तोऽपि ।
कार्ये तत्र विशालां शालामुद्घाटयन्त्येव ॥९१, ९२ ॥

यदि नाम नाऽभविष्यद्विज्ञानानां विलासोऽयम् ।
नूनं जाङ्गलिकत्वमास्थास्यन्मानवेषु सर्वेषु ॥९३॥

विज्ञानमेव सर्वे देशे काले कलाविलासेषु ।
सर्वसमर्पकभावं स्वीकुरुते वा समुन्नतौ पूर्णम् ॥९४॥

क्षुद्रात्क्षुद्रतरेऽप्यथ महतो वा महत्तरे क्षेत्रे ।
विज्ञानेन नितान्तं प्रकाशपातः कृतो दृष्टः ॥९५॥

विज्ञानविनाभावे विज्ञानामपि निरर्थकता ।
संजाताऽसीत्काचिन्नैवाऽद्यत्वे तथा विद्या ॥९६॥

अद्य तु तावत्सर्वा सुलभा पद्धतिरियं जाता ।
नो कठिन्यं गमने कुत्राऽप्याऽस्ते च कस्यापि ॥९७॥

दूरेऽन्तरिक्षगमने दूरे देशान्तरे गमने ।
पुनरप्यथ चाऽऽगमने क्षणेषु यात्रा समाप्नोति ॥९८॥

वाचां विलासकाले ध्वनियन्त्रेणाद्य यत्किञ्चित् ।
साहाय्यं संस्क्रियते वक्तुश्चाऽस्ते महांल्लाभः ॥९९॥

सी० वी० रमणायात्र च श्रद्धाविश्वासपूर्णोऽयम् ।
काव्याञ्जलिः प्रदेयोऽस्माभिः सर्वात्मलाभार्थम् ॥१००॥

शिवदत्तचतुर्वेदस्य काव्यमिदं रमण शतकाख्यम् ।
सी० वी० रमणमहोदयसंस्मृति रूपं मुदं देयात् ॥१०१॥

प्रोफेसर सर सी० वी० रमन : जैसा सुना और देखा

नन्दलाल सिंह

भूतपूर्व अध्यक्ष, स्पेक्ट्रोस्कोपी विभाग
काशी हिन्दू विश्वविद्यालय

आधुनिक वैज्ञानिक युग में यदि प्रश्न किया जाय कि कौन ऐसा भारतीय वैज्ञानिक हुआ है जो निष्ठापूर्वक एवं एकाग्रता के साथ प्रकृति के गूढ़ रहस्यों के उद्घाटन में जीवन पर्यन्त लगा रहा और देश की मानप्रतिष्ठा के साथ अपने नाम और प्रतिष्ठा को विश्व में उजागर किया तो प्रोफेसर चन्द्रशेखर वेंकटरमन का ही नाम सर्वोपरि उद्घोषित होगा। कारण, उन्होंने अपना सारा वैज्ञानिक अनुसंधान भारत भूमि पर किया और सामान्य उपकरणों के सहारे भूमंडल में प्रख्यात रमन प्रभाव (RAMAN EFFECT) की खोजकर अपना एवं देश का नाम अजर-अमर बना दिया। ऐसे मनीषी के साथ रहने और उससे शिक्षा-दीक्षा पाने का अवसर यद्यपि मुझे नहीं प्राप्त हुआ किन्तु दो-चार बार सन्निकट पहुँचने और भाषण सुनने का सुअवसर अवश्य मिला। उनके भाषण सामान्यतया उत्साहवर्धक तथा मनोरंजक होते थे। प्रो० रमन उपस्थिति देख और समझकर अपनी शैली तदनुकूल बनाकर बिना किसी आडम्बर के बोलने लगते और हाव-भाव द्वारा समझाकर मंत्रमुग्ध कर देते थे। भाषण मौलिक होते और उनमें कुछ न कुछ नवीनता की झलक परिलक्षित होती। उनके अनेक शोधपत्रों में से जो थोड़ा बहुत पढ़ सका उससे यही निष्कर्ष निकाला कि प्रोफेसर रमन में अपने अनुसंधान के प्रति अद्भुत निष्ठा और आत्मविश्वास था। कारण, उनका ध्यान प्रायः प्राकृतिक दृश्यों और परिघटनाओं की ओर लगा रहता था। जैसे समुद्र का जल नीला क्यों दिखायी पड़ता है? पक्षियों के डैनों में विभिन्न रंग की आकृतियां कैसे और क्योंकर दृष्टिगोचर होती हैं? मणि-माणिकों में प्रकाश किरणों की रंगावली क्या उनकी रचना पर निर्भर है अथवा प्रकाश ही में उनसे परावर्तित, वर्तित अथवा विवर्तित होने पर कुछ भेद आ जाता है। विभिन्न प्रकार के वाद्य यन्त्रों से स्वर में भेद क्योंकर और कैसे परिलक्षित होता है? आदि।

"होनहार बिरवान के होत चीकने पात"

सामान्य दक्षिणी ब्राह्मण कुल में उनका जन्म 7 नवम्बर सन् 1888 ई० में हुआ। उनके पिता श्री चन्द्रशेखर अय्यर पहले एक स्थानीय पाठशाला में अध्यापक थे। कुछ दिन बाद जब वेंकटरमन तीन वर्ष के थे उनके पिता विजगापतनम् (आंध्रप्रदेश) के एक कालेज में गणित तथा भौतिकी के लेक्चरर नियुक्त हुए। वे अध्यवसायी थे और उनके पास इन विषयों तथा दर्शनशास्त्र की पुस्तकों का भंडार था—पिता जी वायलिन पर स्वर साधन

के भी प्रेमी थे। मेधावी छात्र वेंकटरमन 11 वर्ष की अवस्था में मैट्रिकुलेशन और इण्टरमीडियेट 13 वर्ष की अवस्था में पास कर लिये। दुबले, पतले, क्षीण कृष्ण वर्ण के रमन जब मद्रास प्रेसिडेंसी कालेज में बी० ए० में नाम लिखाकर कक्षा में घुसे तो नंगे पाँव बालक को देखकर प्राध्यापक ने टोका—क्या भूलकर इस कक्षा में आये हो ? उनसे परिचित छात्र हँस दिये। रमन ने अपना प्रवेश पत्र दिखाकर उन्हें आश्वस्त किया। थोड़े ही दिन में अध्यापकों ने उनकी अलौकिक प्रतिभा से प्रभावित होकर उन्हें विज्ञान की कक्षाओं से मुक्त कर दिया। 'तुझे तो सभी बातें स्पष्ट हैं कोई नई बातें बताना ही नहीं, तुम चाहो कक्षा में रहो अथवा जब चाहो न रहो, कोई अन्तर नहीं पड़ेगा"। 15 वर्ष की अवस्था में बी. ए. परीक्षा प्रथम श्रेणी में पास किया। उन्हें अंग्रेजी और भौतिकी में स्वर्णपदक प्रदान किया गया। एम० ए० की परीक्षा इन्होंने 18 वर्ष की अवस्था में सन् 1907 में पास किया।

वेंकट रमन के सभी प्राध्यापक उनकी प्रतिभा एवं विद्वत्ता से प्रभावित थे और उनके चरित्र तथा स्वतंत्र विचार की भूरि-भूरि प्रशंसा करते थे "ऐसा विलक्षण विद्यार्थी अपने वर्षों की शैक्षणिक अवधि में हमें कोई दूसरा नहीं मिला"। छात्र जीवन में ही उनके धारावाही मुहावरेदार भाषण अंग्रेजी में सुनने पर यही विदित होता कि रमन का अंग्रेजी भाषा पर पूर्ण अधिकार है। उनके प्राध्यापक उनकी उच्चतर शिक्षा एवं शोधकार्य के लिए इंग्लैंड भेजना चाहते थे किन्तु मेडिकल डाक्टर ने स्वास्थ्य परीक्षा कर मना कर दिया। कहा कि "वहाँ की कड़ी सर्दी तथा वातावरण में वे जीवित नहीं रहेंगे"। रमन स्वयं इस उद्देश्य से बाहर जाने के इच्छुक नहीं थे। बाद में कभी रमन ने उस मेडिकल डाक्टर के प्रति अपना आभार प्रकट किया "मैं उस डाक्टर महोदय का सदा कृतज्ञ रहूँगा।"

सोलह वर्ष की अवस्था में जब रमन अपनी कक्षा में त्रिपार्श्व (Prism) का कोण सामान्य स्पैक्ट्रोमीटर द्वारा नाप रहे थे, तो उन्हें कुछ विवर्तित स्पेक्ट्रम बैंड (Diffraction bands) दिखाई पड़े। उन्होंने उनका अध्ययन किया और स्वतंत्र रूप से अपना प्रथम शोध पत्र 1906 ई० में लन्दन की फिलासिफिकल मैगजीन (Philosophical Magazine) में छपवाया। इसके तुरन्त बाद उसी मैंगजीन में उन्होंने पृष्ठ तनाव (Surface Tension) नापने की एक नई विधि का प्रकाशन कराया।

श्लाघनीय जीवन

सन् 1906 ई० में एम० ए० पास होते अपने शिक्षकों की प्रेरणा से रमन भारत के वित्त मंत्रालय से सम्बन्धित सिविल सर्विस परीक्षा में सम्मिलित हुए और सर्वप्रथम स्थान प्राप्त किये। वित्त विभाग में उनकी नियुक्ति असिस्टेन्ट

एकाउण्टेण्ट जनरल के पद पर कलकत्ता में हुई। वहाँ रमन अपनी नवविवाहिता पत्नी के साथ स्काट लैन (Scots Lane) में वाउवाजार स्ट्रीट (Bow Bazar Street) से काफी दूर रहने लगे। उस समय उनकी उम्र साढ़े अठारह वर्ष और धर्म पत्नी की उम्र 13 वर्ष की थी। पत्नी को संगीत से प्रेम था और वे वायलिन पर अच्छा स्वर साधन करती थी।

विज्ञान में अभिरुचि

अपने किराये के मकान से दफ्तर रमन ट्राम में बैठकर जाया करते। एक दिन उनकी निगाह एक भवन के द्वार पर पड़ी जिसकी पट्टिका पर "Indian Association for the Cultivation of Science" लिखा हुआ था। दफ्तर से लौटती बार वे उसी स्थान पर रुके और जाकर दरवाजा खटखटाया। वहाँ के एक कार्यकर्त्ता श्री आशुतोष डे ने दरवाजा खोला। दोनों ने एक दूसरे को अपना परिचय दिया। समान विचार के दोनों व्यक्तियों में सह अस्तित्व की भावना जाग्रत हुई। वड़े सम्मान और आदर के साथ आशु वावू ने वेंकट रमन को अन्दर ले जाकर सारी प्रयोगशाला दिखाई। सारा स्थान तथा उपकरणों को धूल धूसरित देखकर रमन को क्षोभ हुआ और आशू वावू के साथ जाकर असोसियेशन के सेक्रेटरी श्री अमृतलाल सरकार से मिले और प्रयोग शाला की वर्तमान स्थिति सुनाकर उसमें प्रयोग करने का अपना विचार प्रकट किये। प्रभावित होकर श्री अमृत लाल सरकार ने चाभियों का गुच्छा उनके हाथ में आदर पूर्वक देकर प्रयोगशाला का समुचित उपयोग करने का अवसर दे दिया।

इस एसोसियेशन की स्थापना श्री अमृतलाल के पिता श्री महेन्द्रलाल सरकार ने सन् 1876 ई० में किया था। वे बड़े उच्च विचार के थे और चाहते थे कि संस्था में Royal Institution London तथा British Association के समान मौलिक शोध कार्य सम्पन्न हो और देश में आधुनिक विज्ञान का विकास हो। इसी वात पर श्री महेन्द्र लाल सरकार निरंतर जोर देते रहे। रोचक एवं जन प्रिय व्याख्यान तथा वैज्ञानिक विषयों पर भाषण तो होते, किन्तु उनके लक्ष्य-विज्ञान-विकास हेतु मौलिक अनुसंधान की पूर्ति ही नहीं होती। वे चाहते थे कि उनके स्थान पर कोई उत्साही नवयुवक आवे और इस असोसियेशन को एक उच्चतम कोटि का अनुसंधान केन्द्र कायम करे। संस्थापक की अभिलाषा की पूर्ति वेंकट रमन ने की।

रमन प्रात: काल 5-30 बजे एसोसियेशन की प्रयोगशाला में जाते और वहाँ से 9-45 पर घर लौटते, स्नान करते, जल्दी-जल्दी भोजन कर टैक्सी से दफ्तर जाते ताकि दफ्तर ठीक समय से पहुँच जांय। शाम को 5 बजे वहाँ से सीधे प्रयोगशाला में जाते

और चार-पांच घंटे काम कर घर 9-30 अथवा 10-00 बजे रात लौटते । रविवार को तो प्राय: पूरा समय प्रयोगशाला में ही व्यतीत करते । स्पष्टत: इस विज्ञान के पुजारी का गार्हस्थ जीवन शुष्क ही रहा ।

यद्यपि उनको वित्त विभाग के कार्य से सन् 1909 में रंगून में रहना पड़ा और सन् 1910 में नागपुर में रहना पड़ा तथापि वहाँ भी वे अपने शोध कार्य में निमग्न रहते । मकान ही में छोटी प्रयोगशाला का जुगाड़ कर लेते । संयोग से सन् 1911 में वे फिर कलकत्ता वापिस आ गये और असोसियेशन की प्रयोगशाला में पूर्ववत् अपना शोध कार्य करने लगे । उस समय प्रयोगशाला में वेंकट रमन और आशू बाबू दो ही व्यक्ति थे फिर भी अनेक शोध प्रबन्ध "Indian Association Bulletin" के नाम से प्रकाशित हुए। सन् 1917 ई० में शोध प्रबन्धों के समुच्चय का प्रकाशन Proceedings of the Indian Association के नाम से होने लगा । वही बहुत दिनों बाद Indian Journal of Physics के नाम से प्रचलित हुआ । वेंकट रमन में दुर्बोध विषयों पर मनन करने और उन्हें साध्य करने की विशिष्ट प्रवृत्ति थी । उनके मस्तिष्क में नये-नये गूढ़ प्रश्न अपने ही अनुभव से प्रस्फुटित होते थे और वे स्वयं उन्हें हल करने में लग जाते थे । यही उनमें विशिष्टता थी । उन्होंने सुना था कि पिता जी वायलिन बजाते थे। उन्होंने अपनी धर्मपत्नी को वायलिन पर स्वर-साधन करते देखा । कालेज में उन्होंने सोनोमीटर तथा मेल्डी के प्रयोग (Melde's Experiment) किया था जैसे सभी छात्र प्रयोग करते ही हैं किन्तु रमन प्रयोग करते मन ही मन उनकी क्रिया विधि पर सचेष्ट होकर विचार करते रहते । उनके कर्ण-पटन संवेदनशील हो गये थे अत: स्वरों में भेद वे तुरन्त पकड़ लेते थे । निजी अनुभव से उन्होंने अनेक शोध प्रबन्ध सारंगी, सितार, वायलिन, बाँसुरी आदि वाद्ययंत्रों पर प्रकाशित किया । नदी और समुद्र की लहरों की छपक (Splashes) में भेद, सुरीली ज्वाला, तप्तधातुओं की मंदध्वनि आदि की क्रियाविधि का सैद्धान्तिक विवेचन करने में नहीं चूके। वीणा और तबला के स्वरों का भी गहन अध्ययन किया । इन समस्याओं को उन्होंने गौण नहीं माना । उन्होंने दिखाया कि मृदंग और तबले पर कुछ लेप लगाकर अति संवादी स्वर निकाले जा सकते हैं जो तार के वाद्ययंत्रों के स्वर के समान हो जाते हैं ।

सर आशुतोष मुकर्जी स्मृति ग्रंथ (Commemoration Volume) में उनका एक उच्चकोटि का शोध प्रबन्ध "प्राचीन भारत की गायन कला" पर प्रकाशित हुआ जिससे वेंकट रमन ध्वनि तथा वाद्ययंत्रों के विश्वविख्यात विशेषज्ञ प्रमाणित हुए । इस प्रकाशन के कुछ पहले कलकत्ता विश्वविद्यालय के कुलपति सर आशुतोष मुकर्जी ने उन्हें Palit chair of Physics के पद पर आसीन होने के लिए आग्रह किया । विज्ञान के पुजारी वेंकट रमन अपने उच्च आर्थिक लाभ तथा गौरवशाली एकाउन्टेंट जनरल के पद को त्याग कर कम वेतन के इस पद को सहर्ष स्वीकार कर लिया । वित्त विभाग में

वेंकट रमन की वड़ी ख्याति थी। उनके वरिष्ठ अधिकारी यह सुनकर खेद प्रकट किये। वे रमन की कार्य निष्ठा की सराहना करते हुए कहने लगे कि (रमन) वित्त विभाग के लिए अत्यन्त उपयोगी हैं। सर्वश्रेष्ठ अधिकारियों में एक निराले व्यक्ति हैं। यहाँ उन्नति करते वे वाइसराय की सहकारी समिति के वित्त सदस्य (मंत्री) हो सकते हैं किन्तु रमन इस प्रलोभन में नहीं पड़े। अपने निर्णय पर अडिग रहे।

पालित चेयर पर नियुक्त होने की एक शर्त थी कि व्यक्ति की विदेश में ट्रेनिंग हुई हो। वेंकट रमन ने विलायत जाकर ट्रेनिंग लेने से इनकार कर दिया। दूरदर्शी एवं कुशल प्रशासक सर आशुतोष मुकर्जी ने जो वेंकट रमन की विलक्षण प्रतिभा से प्रभावित थे अग्रहार दान पत्र (Endowment) के नियमों में संशोधन कराकर रमन की नियुक्ति पालित चेयर पर करा ही लिए।

सन् 1919 में श्री अमृतलाल सरकार के निधन के वाद वेंकट रमन असोसियेसन के आनरेरी सेक्रेटरी हो गये। अव उनके अधीन दो प्रयोगशालयें आ गई। अव तक उनके साथ अकेले आशु वावू थे। अब रमन ने अपने साथ चुनकर कई अन्य शोध छात्रों को सहयोगी वना लिया। सन् 1921 में आक्सफोर्ड में विश्वविद्यालयों की कांग्रेस हुई। उसमें सर आशुतोष मुखर्जी ने उन्हें कलकत्ता विश्वविद्यालय का प्रतिनिधि वनाकर भेजा। इंगलैंड के धुरंधर वैज्ञानिकों जैसे जे० जे० टामसन, रूदरफोर्ड, ब्रेग (सीनियर) आदि से भेंट हुई। रुदरफोर्ड उन्हें पहचान कर अपने वगल की कुर्सी पर वैठाये। वेंकट रमन की झिझक दूर हुई वे गदगद हो गये। पर्यटकों के साथ सेंट पाल चर्च, व्हिस्परिंग गैलरी तथा कई रमणीक स्थानों सहित प्रयोगशालाओं के भी निरीक्षण किये और कुछ प्रयोग भी अपनी इच्छानुसार कर दो शोध पत्र प्रकाशित किये। इस यात्रा में सामुद्रिक जहाज़ से जाते आते भूमध्यसागर के जल की नीलिमा देखकर अत्यन्त आह्लादित हुए। उनके मस्तिष्क में लार्ड रैले (Lord Rayleigh) की गहरे जल की नीलिमा की व्याख्या उद्वेलित होने लगी। लार्ड रैले ने वताया था कि आकाश नीला वायुमंडल के अणुओं द्वारा प्रकाश के प्रकीर्णन से दिखाई पड़ता है। और गहरे जल में उसी नीले आकाश की परावर्तित छाया पड़ती है जिससे जल नीला दिखाई पड़ता है।

वेंकट रमन लार्ड रैले की व्याख्या से संतुष्ट नहीं थे। उन्होंने जहाज ही पर एक साधारण प्रयोग करना शुरू किया। अपने साथ सदा कुछ न कुछ प्रायोगिक साधन रखते थे। उन्होंने Nicol Prism निकाला और उसे इस प्रकार आयोजित किया कि जल से परावर्तित तथा इस कारण ध्रुवित प्रकाश किरणों को यह पारगमित न करें। ताकि जल में आकाश की परावर्तित छाया एकदम लुप्त हो जाय, दिखाई न पड़े। ऐसी स्थिति में उन्होंने जल की सतह पर प्रत्यक्ष नीलिमा देखा जो जल के भीतर से आती मालूम पड़ी। उन्होंने तुरन्त निष्कर्ष निकाला कि "नीलिमा भीतरी जल के अणुओं द्वारा प्रकाश के प्रकीर्णन से

उत्पन्न होती है।" उन्होंने आगामी प्रयोगों को ध्यान में रखकर कई बोतलों में विभिन्न गहराई से समुद्र जल एकत्र किया। अन्य यात्री जब जहाज पर रमन की शारीरिक तथा मानसिक चहल-पहल से विस्मित हो रहे थे कि यह पगड़ी वाला कैसा खेलवाड़ कर रहा है? विज्ञान के मसीहा रमन अपने आगामी प्रयोगों तथा सिद्धान्तों के चिन्तन में निमग्न थे कि इस निष्कर्ष की पुष्टि किस प्रकार किया जा सकेगा।

स्वदेश लौटकर उन्होंने तीन तरह के अत्यन्त उपयोगी अन्वेषण प्रारम्भ किया।

1—द्रवों में प्रकाश प्रकीर्णन

2—द्रवों द्वारा *x* — किरणों का प्रकीर्णन

3— द्रवों की श्यानता (Viscosity) मापन

इंगलैड से लौटते ही प्रो० रमन ने श्री रामनाथन तथा अन्य कई शोध छात्रों का द्रवा में एक्स किरणों के प्रकीर्णन के अध्ययन में लगाया। ऐसा प्रयोग सर्वप्रथम भारतवर्ष ही में नियोजित हुआ। रमन-रामनाथन ने सन् 1923 ई० में अपने इन प्रयोगों के आधार पर तथा द्रव संरचना सम्बन्धी अनुमानित सिद्धान्त का निरूपण एक महत्वपूर्ण शोध प्रबन्ध में प्रकाशित किया। इसमें कई अणुओं के आकार तथा समान अणुओं के सामूहिक व्यवहार तथा उनकी पारस्परिक क्रिया का द्रव स्थिति में सैद्धान्तिक विवेचन किया गया किन्तु प्रो० रमन का ध्यान तो प्रकाश-प्रकीर्णन पर ही केन्द्रित रहा। उस महत्वपूर्ण शोध प्रबन्ध का उपयोग करके सन् 1927 में Zernike और Prins ने फोरियर रूपान्तरण (Fourier Transform Theory) लगाकर द्रव में अणु-समूह की संरचना का निर्धारण करने में सफलता पाई।

इसी प्रकार श्यानता (Viscosity) का मापन कई द्रवों में विभिन्न परिस्थितियों में कर कराकर सन् 1923 में प्रो० रमन ने श्यानता सिद्धान्त का प्रतिपादन किया पर इस सिद्धान्त का भी उपयोग प्रसिद्ध पालीमर (Polymer) वैज्ञानिक Staudenger ने किया और वहुलायवय (Polymers) की श्यानता की व्याख्या प्रस्तुत की।

उसी समय प्रो० रमन ने श्री शेषगिरि राव (Seshagiri Rao) के साथ जल में अणुओं द्वारा प्रकीर्णित प्रकाश-किरणों की तीव्रता का मापन किया और इस निष्कर्ष पर पहुँचे कि आणविक प्रकीर्णन की व्याख्या Einstein-Smoluchowski के उष्मागतिक उच्चावचन (Thermodynamic Fluctuation) सिद्धान्त द्वारा की जा सकती है। इस विचार से उन्होंने कई शोध छात्रों को द्रवों तथा वाष्पों में आणविक प्रकीर्णन के अध्ययन में नियोजित किया और इन प्रयोगों के आधार पर अत्यन्त महत्वपूर्ण प्रबन्ध (The Molecular Diffraction of Light) प्रकाशित किया। इस शोध प्रबन्ध से रमन के मस्तिष्क

की ऊहापोह की झलक मिलती है। स्वतः कई प्रश्न वे द्रव्य के अणुओं और प्रकाश किरण की ऊर्जा के आदान-प्रदान में उठाते रहे। क्या ऐसी प्रक्रिया में प्रकाश-क्वांटम की ऊर्जा और अणु की ऊर्जा में परिवर्तन होना सम्भव है? मालूम पड़ता है कि प्रो० रमन को विश्वास होने लगा था कि प्रकाश की क्वांटम प्रकृति से प्रकीर्णन की क्रिया-विधि का निरूपण किया जा सकता है। इसी के एक साल वाद काम्पटन ने x—किरण की ऊर्जा तथा पदार्थ के इलेक्ट्रान की ऊर्जा में आदान-प्रदान की रीति काम्पटन प्रभाव (Compton Effect) में प्रतिष्ठित किया।

अप्रैल 1923 में प्रो० रमन अपने शोध छात्रों के साथ फिर प्रकाश प्रकीर्णन का अध्ययन एकनिष्ठ भाव से करने लगे। उनके प्रथम शोध छात्र प्रख्यात डा० के० आर रामनाथन जल में प्रकाश प्रकीर्णन का प्रयोग आदेशानुसार करने में तत्पर हुए। केन्द्रित सूर्य-प्रकाश जल पर एक दिशा से आपतित कराते और प्रकीर्णित रश्मियों का निरीक्षण उसके अभिलम्ववत करते। उन्होंने पूरक फिल्टरों (Complementary Filters) का समुदाय तैयार किया। समुदाय में कई वर्ण की पूरक फिल्टरों की जोड़ी थी। जोड़ी की एक फिल्टर से जो वर्ण पारगमित होता वह दूसरे द्वारा पूर्णरूप से छन जाता (स्तब्ध हो जाता-अवरुद्ध हो जाता)। इस आयोजन का उद्देश्य यह था कि जोड़ी के एक फिल्टर से पारगमित प्रकाश जल पर आपतित होकर प्रकीर्णित होगा और प्रकीर्णित प्रकाश का अभिलम्ववत दिशा में दूसरे को लगाकर निरीक्षण किया जायेगा तो कोई प्रकाश रेखा नहीं दिखाई देगी किन्तु हर बार ऐसे प्रयोग में क्षीण प्रकाश रेखा दिखाई पड़ती थी। सम्भवतः यह अति मन्द्र प्रकाश रेखा जल की अशुद्धियों की दीप्ति (Fluoresecnce) से उत्पन्न होती हो। जल को कई वार निर्वात स्रवण कर विशुद्ध किया गया तव भी क्षीण प्रकाश रेखा विद्यमान देखी गई साथ ही रेखा पूर्ण निध्रुवित नहीं थी जैसा कि दीप्ति रश्मियाँ होती हैं। अब प्रो० रमन के मन में धारणा हुई कि हो न हो प्रकीर्णन जल के अणुओं से संवन्धित काम्पटन प्रभाव (Compton Effect) के सदृश कोई भौतिक परिघटना हो।

सन् 1928 में डा0 वेंकटेश्वरन कई द्रवों का निर्वात में स्रवण कर उसी रीति से प्रकीर्णित प्रकाश का निरीक्षण कर रहे थे। उन्होंने देखा कि विशुद्ध ग्लिसरीन द्वारा प्रकीर्णित प्रकाश नीला न होकर हरा दिखाई पड़ रहा है और विकिरण पूर्णतया ध्रुवित है। इस निरीक्षण से प्रभावित होकर प्रो० रमन ने अपने दूसरे प्रतिभाशाली छात्र डा०के०एस० कृष्णन को ऐसे प्रयोग जैविक द्रवों पर करने का आदेश दिया।

डा० के० एस० कृष्णन प्रयोग करने में प्रवीण थे। उन्होंने सूर्य प्रकाश को 7 इंच व्यास के लेन्स द्वारा केन्द्रित कर द्रव पर आपतित प्रकाश की तीव्रता बढ़ाया और अनेक जैविक द्रवों तथा उनके वाष्प में प्रकाश प्रकीर्णन का अध्ययन किया। सभी द्रवों के प्रकीर्णन मे उन्हें तथाकथित 'मंद दीप्ति' रेखा, जिसका निरीक्षण सर्वप्रथम डा० रामनाथन ने किया

था पर्याप्त प्रखर एवं स्पष्ट दिखाई पड़ीं । उन्होंने यह भी देखा कि सभी द्रवों द्वारा प्रकीर्णित रेखा ध्रुवित है और उनकी ध्रुवता द्रवों के अणुओं की विषम दैशिकता (Molecular Anisotropy) पर निर्भर है । ध्रुवण की मात्रा अणु की विपम दैशिकता का विलोमी पाई गई ।

प्रो० रमन ने इन सभी द्रवों में प्रकाश-प्रकीर्णन का प्रयोग स्वयं किया और डा० कृष्णन के निरीक्षणों को सही पाकर संतुष्ट ही नहीं प्रफुल्लित एवं उत्साहित होकर सीधे कृष्णन के निवास स्थान पर गये । उनके मस्तिष्क में परिघटना सम्बन्धी सैद्धान्तिक निरूपण का ऊहापोह होता ही रहा । बोले "हम लोगों ने जो प्रकीर्णन परीक्षण किया है वह क्रेमर्स-हाइजनवर्ग की क्रिया-विधि के अनुकूल ही है ।" उन्होंने तुरन्त अपने अनुसंधान पर एक टिप्पणी Nature पत्रिका को भेजा । Modified Radiation could arise from the fluctuations of the molecules from the Normal state. (प्रकीर्णन द्वारा उत्पन्न परिवर्तित विकिरण सम्भवत: अणुओं के अपने सामान्य स्थिति से उच्चावचन से प्रकट होती है ।) उन्होंने काम्पटन प्रभाव (Compton Effect) की व्याख्या चिरसम्मत यांत्रिकी के आधार पर किया था और एक महत्वपूर्ण शोध पत्र प्रकाशित किया था । उनके अनुसार जैसे एक्स किरण परमाणुओं के उच्चावचन से प्रकीर्णित परिवर्ती किरण निकलती है उसी तरह यहाँ अणुओं के उच्चावचन से प्रकीर्णित प्रकाश परिवर्तित रूप में प्रकट होती है । यह तुलनात्मक विवेचन यद्यपि ठीक मालूम पड़ा किन्तु परिघटना का रहस्य स्पष्ट नहीं हो सका । अतः अन्य प्रयोगों का क्रम चलता रहा जिनमें प्रो० रमन स्वयं तल्लीन रहे ।

28 फरवरी 1928 को प्रो० रमन ने तथाकथित 'प्रतिदीप्ति प्रकाश रेखा' का निरीक्षण Direct Vision Spectroscope से किया । उन्हें स्पेक्ट्रम में न केवल आपतित प्रकाश रश्मि की प्रखर रेखा दिखाई पड़ी बल्कि एक अन्य स्पष्ट रेखा कुछ अन्तराल पर दिखाई पड़ी । रमन प्रभाव (Raman Effect) तत्क्षण वास्तविक सिद्ध हुआ ।

प्रो० रमन ने तुरन्त आशु बाबू को मरकरी आर्क (MercuryArc) ठीक करने को कहा क्योंकि इस स्रोत के संदर्भ में कई प्रखर एवं तीक्ष्ण रेखायें मिलती है । आर्क की सभी 4358 A^0 से अधिक तरंगदैर्ध्य की रेखाओं को अनुकूल फिल्टर द्वारा स्तब्ध कर (छानकर) आपतित प्रकाश के अभिलम्ववत डाइरेक्टविजन स्पेक्ट्रोस्कोप से प्रकीर्णित प्रकाश देखा गया तो नीले-हरे क्षेत्र में दो प्रखर एवं तीक्ष्ण रेखायें स्पष्ट दिखायी पड़ी— अब इस परिघटना की सत्यता पर रंचमात्र सन्देह नहीं रहा और दूसरे ही दिन 29 फरवरी 1928 को रमन-प्रभाव (Raman Effect) की घोषणा सभी दैनिक समाचार पत्रों द्वारा की गई ।

इसके बाद स्पेक्ट्रम—Hilger Baby Quartz Spectrograph द्वारा लिया गया और नयी रेखा का मूल रेखा से अन्तराल ठीक-ठीक मापा गया। मूल रेखा की अपेक्षा नवीन रेखा की (Frequency) आवृत्ति संख्या को समतुल्य ऊर्जा अणु की दोलनीय स्तर की ऊर्जा के ठीक समान पायी गयी। सूक्ष्मतर प्रयोगों से विदित हुआ कि मूल रेखा के दोनों ओर एक-एक नवीन रेखा समान अन्तराल पर प्रकट होती है। विदित हुआ कि आपतित फोटान प्रकीर्णक अणु को अपनी ऊर्जा देता और उससे लेता भी है।

कहा जाता है कि Nature पत्रिका ने इस नवीन अनुसंधान को प्रकाशित करने से इनकार कर दिया किन्तु जब उसके सम्पादक ने जान्स हापकिंस यूनिवर्सिटी के विश्व-विख्यात प्रो० आर० डब्लू० उड (Professor R. W. Wood) की इस नवीन अनुसंधान पर निम्नलिखित टिप्पणी पढ़ा तो शर्मिदा हुआ और घोषणा प्रकाशित किया।

प्रो० रमन का अद्‍भुत एवं अत्यन्त महत्त्वपूर्ण अनुसंधान

"मैंने रमन के प्रयोग को स्वयं किया है और अनुसंधान को जाँच हर प्रकार से किया है। इन नवीन अनुसंधान से अवरक्त (Infrared) स्पेक्ट्रम क्षेत्र का अध्ययन सुगम होगा। इतना ही नहीं इससे क्वाँटम सिद्धान्त की पुष्टि होगी। यह प्रो० रमन के वर्षों (1921-1928) के सतत् प्रयास का फल है। इस अनुसंधान की उपयोगिता विज्ञान के विभिन्न क्षेत्रों में असीम है।"

वास्तव में रमन प्रभाव की घोषणा होते ही दुनिया की प्रमुख प्रयोगशालाओं में इसका अध्ययन छोटे-मोटे सरल अणुओं पर होने लगा किन्तु रमन की प्रयोगशाला में पदार्थों की द्रव तथा ठोस अवस्था की संरचना जैसी मौलिक समस्याओं पर ही अन्वेषण होता रहा। कई प्रकार के सुग्राही रमन स्पेक्ट्रोग्राफ तथा अनुलेखी स्पेक्ट्रोमीटरों (Recording Raman Spectrometers) का निर्माण हुआ और उनके द्वारा साधारण एवं जटिल से जटिल अणुओं की संरचना तथा उनकी भौतिक एवं रसायनिक क्रियाओं का अध्ययन होने लगा। आज विज्ञान का कोई क्षेत्र नहीं है जिसमें रमन प्रभाव का उपयोग अणु संरचना में इन उपकरणों द्वारा न होता हो।

सन् 1930 ई० के दिसम्बर मास में प्रो० रमन को 'रमन प्रभाव तथा प्रकाश क्षेत्र में उनके अन्य अनुसंधानों' के उपलक्ष्य में सर्वश्रेष्ठ नोबेल पुरस्कार (Nobel Prize) प्राप्त हुआ। भारत वर्ष गौरवान्वित हुआ तथा इस अनुपम अनुसंधान से उनके नाम के साथ भारत देश का नाम अजर अमर हो गया। पुरस्कार प्राप्ति की भविष्यवाणी रमन ने 1924 में Royal Society का सदस्य बनते ही दृढ़तापूर्वक अपने भाषण में की थी।

सन् 1933 में प्रो० रमन को टाटा इन्स्टीट्यूट (Indian Institute of Science) बंगलौर का डाइरेक्टर पद अर्पित हुआ। उन्होंने कलकत्ता में I.A.C.S. को प्रख्यात रिसर्च सेन्टर वना दिया था। चुने हुए शोध छात्र अपने अपने कार्य में प्रगति कर रहे थे। प्रो० रमन वड़े असमंजस में पड़े; किन्तु विज्ञान क्षेत्र और वैज्ञानिक वातावरण प्रसारित करने के उद्देश्य से अपने प्रतिभाशाली कुशाग्र छात्र डा० के० एस० कृष्णन को इन्डियन एसोसियेशन में Mahendra Lal Sirkar Chair पर नियुक्त कराकर बंगलौर गये और वहाँ भी कलकत्ता के समान वैज्ञानिक वातावरण कायम किये। विशेषकर भौतिकी विभाग का नाम विश्वविख्यात हुआ। सन् 1934 ई० में Indian Academy of Science की स्थापना किये। उल्लेखनीय शोध प्रबन्ध के प्रकाशन से अकादमी का नाम विश्वविख्यात हुआ। विज्ञान के हर एक क्षेत्र के वैज्ञानिकों को उनके शोध प्रबन्धों का मूल्यांकन कर एकेडमी का फेलो वनाया गया। उसी समय जर्मनी के कई शीर्षस्थ वैज्ञानिक हिटलर के प्रतारण से भयभीत होकर अपना देश छोड़ कर भाग निकले। उनको प्रो० रमन ने बंगलौर आने के लिये आमंत्रित किया ताकि भारत में यूरोप के समान विज्ञान का विशुद्ध वातावरण कायम हो और होनहार छात्रों को विज्ञान की शिक्षा-दीक्षा अपने ही देश में कराया जाय और देश में मौलिक अनुसन्धान हो सके। प्रो० रमन कुशाग्र विद्यार्थियों को खोजकर अपनी प्रयोगशाला में रखने के लिये सदा उत्सुक रहते थे। उन्हे विदेश भेजने के पक्ष में नहीं थे, कारण वे उन्हें वाहर भेजने में देश के धन का अपव्यय समझते और देखते कि बाहर से शिक्षित-दीक्षित होकर लौटने पर उनमें मौलिक शोध करने की क्षमता नहीं विकसित होती। उनके निमंत्रण पर केवल प्रो० मैक्सवार्न बंगलौर आये। अन्य वैज्ञानिक इंगलैड, अमेरिका जा वसे। यह कार्यवाही प्रो० रमन अपने अनूठे स्वभाव के अनुसार स्वतंत्ररुप से किये थे। प्रबन्धकारिणी से कोई राय वात नहीं किये। सदस्यों ने अनुशासनहीनता का दोष लगाकर उन्हें डाइरेक्टर पद से च्युत कर दिया किन्तु प्रोफेसर पद पर आसीन रहने दिया। प्रो० रमन को इन्स्टीट्यूट के प्रशासनिक कार्यों से छुट्टी मिली और वे अपने अनुसंधान कार्य में एकाग्र चित्त से अपने छात्रों के साथ संलग्न हुए। उनके आदेशानुसार प्राय: चिड़ियों के रंग विरंगे डैनों, सीप (Sea shells) और पुराने विभासी रंगदार काँच आदि से निसृत प्रकाश पर तथा रमणीक प्राकृतिक दृश्यों पर शोध होता रहा।

डा० नागेन्द्रनाथ के साथ उन्होंने अल्ट्रासानिक (कर्णातीत) तरंगों पर प्रकाश विवर्तन (Diffraction) का अध्ययन किया और एक महत्वपूर्ण शोध प्रबन्ध रमन-नाथ के नाम प्रकाशित हुआ। उन्होंने इसमें एक अत्यन्त सरल अवधारणा का समावेश किया था। अल्ट्रासानिक तरंग में भी एकान्तरक्रम से संपीडन (Compression) तथा विरल (Rarefaction) स्थितियाँ होती हैं। जव समतल प्रकाश तरंग सघन क्षेत्र से गुजरती है तो वेग में कमी आ जाती है और जव विरल क्षेत्र से होकर निकलती है तो वेग में वृद्धि होती है। फलस्वरूप निस्सृत प्रकाश का अग्र (front) आरीदाँत (Saw Toothed) के समान हो जाता है। इस शोध प्रबन्ध का अभूतपूर्व स्वागत विज्ञान क्षेत्र में हुआ और

कई प्रचलित सिद्धान्तों का शमन हुआ। इसके छपते ही अनेक शोध प्रबन्ध इस विषय पर प्रकाशित हुए।

उसी समय बंगलौर के भौतिकी विभाग में द्रव में प्रकाश प्रकीर्णन की प्रक्रिया पर भी विचार विनिमय होता रहा। वृलो (Brillonin) सिद्धान्त के अनुसार द्रव में उष्मागतिक उच्चावचन का विभाजन फुरियों खंडों (Fourier Components) में किया जा सकता है जिससे प्रकीर्णित प्रकाश में स्थानान्तरण (Shift) डाप्लर प्रभाव के कारण हो जाता है और इस स्थानान्तरण का मापन कर तरंग वेग ज्ञात किया जा सकता है। किन्तु साथ ही एक अद्भुत बात का पता लगा कि इन उच्च आवृत्ति की तरंगों से स्निग्ध द्रवों का व्यवहार ठोस स्थिति के अनुरूप हो जाता है जिससे उनमें अनुधैर्य तरंग के साथ विरूपित तरंग का भी समावेश होता है। अतः इन उच्च आवृत्ति तरंगों द्वारा द्रव का दृढ़ता मापांक (Rigidity Modulus) ज्ञात किया जा सकता है।

प्रोफसर रमन मणिभ संरचना के भी अनुरागी थे। प्रयोग करने के लिये बड़ी मात्रा में बहुमूल्य मणिभ इकट्ठा किया था। हीरा (Diamond) पर प्रकाश किरणों के कई प्रयोग किये थे और उन्हीं अनुभव के आधार पर उसकी संरचना पर मनन करते, प्रकृति के कलात्मक सौन्दर्य पर विभोर हो जाया करते थे। उसी सिलसिले में पदार्थ की ठोस अवस्था के कई भौतिकी गुणों के परिमाणिक मापन किये गये और उनमें द्वितीय कोटि का रमन प्रभाव (Second Order Raman Effect) तथा उनके अवरक्त स्पेक्ट्रम (Infrared Spectrum) पर भी गहन अध्ययन हुआ। सम्भवतः X—किरण द्वारा उनका स्थानीय निरुपण (X-ray Topography) का आविष्कार उसी प्रयोगशाला में हुआ। प्रो० रमन के उर्वरा मस्तिष्क की प्रगाढ़ता का आकलन सम्भव नहीं। उनकी प्रतिभा बहुमुखी थी। उनका व्यक्तित्व निराला था। स्वाभिमानी तो थे ही उनमें देश प्रेम तथा देशाभिमान कम नहीं था—भारतीय संस्कृति में उनकी पूरी आस्था थी। गलेवन्द लम्बे कोट और पैंट के साथ सिर पर पगड़ी सदा पहनते थे। विदेश यात्रा में भी उनके इस पहनावा में कोई अन्तर नहीं पड़ता था। सन् 1924 ई० से लेकर सन् 1954 ई० तक प्रो० रमन में अनेक होनहार छात्रों को प्रोत्साहित किया। उनमें कई छात्र अपनी योग्यता तथा रमन की उदार चेष्टा से उच्चतम पद प्राप्त किये। प्रो० रमन अपने भाषण में जहां कहीं अपने गवेषणाओं का विवरण सुनाते अपने सहयोगियों के कार्य की सराहना करने में न चुकते। वे एक महान व्यक्ति थे। एक आदर्श व्याख्याता थे। भाषण देने में उन्हें किसी विशेष साधन सामग्री जुटाने की आवश्यकता नहीं पड़ती थी। अपने शोध परिणामों को तथा अपनी अन्तर्मन की धारणाओं को व्यक्त करने के लिये सदैव तत्पर रहते थे। निर्भीक किन्तु संयमित वक्ता थे।

सन् 1948 ई० में प्रोफेसर रमन इण्डियन इस्टीट्यूट से साठ वर्ष की अवस्था पर अवकाश ग्रहण किये। भारत सरकार ने उन्हें राष्ट्रीय प्रोफेसर (National Professor) पद से आभूषित किया किन्तु स्वाभिमानी प्रो० रमन ने उसी समय निजी शोध संस्थान स्थापित करने का संकल्प लिया। आर्थिक संकट था किन्तु भारत सरकार तथा प्रादेशिक सरकार से याचना करना अपनी हीनता समझा वरन् अपने संकल्प पर दृढ़ता पूर्वक आरूढ़ रहे। उन्हें पं० मदन मोहन मालवीय के आदर्श मार्ग पर चलकर संस्था के लिए भिक्षाटन ठीक लगा। देश में घूम-घूम कर संस्था निर्माण का उद्देश्य जनता को बताते। उन्होंने पर्याप्त धन एकत्र किया और उसका निर्माण पूरा करा लिया फिर भी बिजली, पानी तथा अन्य साधनों की व्यवस्था होना नितांत आवश्यक था। उनकी पूर्ति के लिए प्रो० रमन ने अपने कुछ पुराने छात्रों के सहयोग से दो रासायनिक फैक्टरियाँ खोला और उनके लाभांशों से धीरे-धीरे नये संस्थान की आवश्यकताओं की पूर्ति की। तदनन्तर उपकरणों को खरीदने के लिए अधिक धन की आवश्यकता पड़ी। सोच में पड़े, किन्तु जनता के सामने दुबारा हाथ फैलाना उचित नहीं समझा। उनका ध्यान अपने मणियों पर गया। अपने शोध कार्य के लिये बहुत कीमती मणिभ जैसे हीरा, मोती, रूबी, पन्ना आदि का संग्रह अधिक मात्रा में कर रखा था। उन्होंने उन सबको बेचकर पर्याप्त धन प्राप्त किया और आवश्यकतानुसार उपयुक्त उपकरणों की खरीद की।

प्रोफेसर रमन ने कभी बहुत अधिक समितियों के सदस्य बनने की इच्छा नहीं की। अब जिन दो-चार समितियों के मनोनीत सदस्य थे उनसे भी विरक्त हो गये और एक निष्ठता से नई संस्था को विकसित करने में तल्लीन हुए। यह तीसरा संस्थान भी रमन इन्स्टीट्यूट के नाम से विज्ञान जगत में ख्याति प्राप्त किया।

भारत सरकार ने एक विश्वस्त सूत्र द्वारा एक प्रलोभन दिया कि प्रो० सी० वी० रमन भारत के उपराष्ट्रपति का पद ग्रहण कर लें तो देश का बड़ा कल्याण हो। खबर पाते ही प्रो० रमन हँस पड़े और कहे "उस पद को लेकर मैं क्या करूँगा"। प्रो० रमन ने कभी देश के किसी प्रशासनिक पद पाने की इच्छा नहीं किया। वे देश की राजनीति के मायाजाल में कभी नहीं पड़े। उन्होंने तो प्रारम्भ में ही विज्ञान सेवा के लिए एकाउण्टेण्ट जनरल का अत्यन्त लाभदायक पद ठुकरा दिया था। उन्हें यावत् जीवन विज्ञान-धर्म के पालन में आनन्द मिलता रहा।

प्रोफेसर रमन के मन में महामना मालवीय जी तथा उनके काशी हिन्दू विश्वविद्यालय के प्रति असीम श्रद्धा थी। मालवीय जी भी एक विलक्षण पारखी थे। सदा उच्च श्रेणी के विद्वानों की खोज में रहते और उनकी भनक पाते ही उन्हें विश्वविद्यालय की सेवा में किसी न किसी रूप से नियोजित करते। स्वदेश प्रेमी प्रोफेसर रमन को उन्होंने अनेक बार विश्वविद्यालय में आमंत्रित कर भाषण कराया था। वार्षिक दीक्षान्त

समारोह में मुख्य अतिथि के रूप में सम्मानित कर उन्हें विज्ञान की आदरी डाक्टरेट की उपाधि से विभूषित किया और आजीवन भौतिकी का आदरी प्रोफेसर नियुक्त कर दिया था। जब कभी प्रोफेसर सर सी० वी० रमन के आगमन की सूचना होती तो विभाग में उत्साह की लहर के साथ खलबली मच जाती। कुछ लोग भयभीत होते तो अन्य अपने छात्रों सहित अपना कार्य दिखाने तथा निजी समस्याओं के उनके परामर्श से हल पाने की आशा से उत्सुक होते। प्रायः सभी उनके व्यक्तित्व से प्रभावित सहमे रहते किन्तु रमन सबकी बाते सुनते और गौर करके उचित सलाह देते। सन् 1941 ई० में एक वार ऐसे ही अवसर पर प्रोफेसर असुंडी के साथ मेरे कमरे में घुस आये। मैंने कुछ स्पेक्ट्रम Baby Quartz Spectrograph पर लिया था- उनकी तीखी नजर एक स्पेक्ट्रम प्लेट पर पड़ी जिसमें iron arc spectrum मापन के लिये मुख्य स्रोत के स्पेक्ट्रम के साथ लिया गया था। "Hello Asundi, how do you identify hundreds of spectral lines ? चकित किन्तु सहज भाव से पूछे प्रश्न का उत्तर प्रोफेसर असुंडी ने उसी आदर भाव से दिया। स्पेक्ट्रोग्राफ का नाम सुनकर रमन प्रसन्न मुद्रा में बोल उठे। इसी स्पेक्ट्रोग्राफ पर जब रमन प्रभाव (Raman effect) की पुष्टि हुई तभी उसकी घोषणा की गई थी। मैं मूक दोनों महानुभावों की वार्ता सुनकर विस्मित हुआ। अरे ऐसे छोटे उपकरण से रमन प्रभाव की खोज हुई।

प्रोफेसर रमन महामानव थे। उनकी मानवता की झलक दूसरी वार रमन इन्स्टीट्यूट वंगलौर में ही मिली। वंगलौर में C. S. I. R. की मीटिंग हुई। मैं उसी मीटिंग में सम्मिलित होने गया था। उसी मिटिंग में हमारे पूज्य गुरुदेव, प्रोफेसर रंगा कृष्ण असुडी भी वम्बई से आये थे। मीटिंग समाप्त होने पर उनकी इच्छा प्रोफेसर रमन का दर्शन करने को हुई। हम लोग रमन इन्स्टीट्यूट गये। वहाँ प्रोफेसर रमन अपनी तीसरी शोध संस्था पूर्णरुप से स्थापित कर चुके थे। उपकरणों से सुसज्जित प्रयोगशाला के साथ विशाल पुस्तकालय (Library) था जिसमें विज्ञान के विभिन्न विषयों के जर्नल तथा उच्चतर स्तर के ग्रंथ उपलब्ध थे। प्रो० रमन ने उसी संस्थान को अपना निवास स्थान बना लिया था। वहीं स्वाध्याय तथा अनुशीलन करते शोध कार्य का निर्देशन एवं निरीक्षण करते रहते। आगन्तुकों से मिलने-जुलने पर प्रतिबंध लगा था किन्तु प्रो० असुंडी ने जब अपना परिचय पत्र भेजा तो सहर्ष अपने निजी कक्ष में बुलवा लिये। मैं भी साथ घुस गया। देखते ही प्रोफेसर रमन उठ खड़े हुए और Hello Asundi, How do you do ? कहते उन्हें बड़े प्रेम से गले लगा लिए। मुझे उनका मिलन राम-भरत मिलाप जैसा लगा-दोनों प्रेम-विभोर थे। असुंडी उनके पाँव छूने झुके किन्तु रमन उन्हें वक्षस्थल से नीचे घिसकने नहीं दिये। मैंने उनके चरण छूये--गुरू जी ने मेरा परिचय दिया। वनारस यूनिवर्सिटी का नाम सुनते गदगद् हो गये। Oh the great Banaras Hindu University, founded by Pt. Madan Mohan Malviya, the great visionary. तुरन्त अपनी कुर्सी के पीछे कीबड़ी आलमारी खोले—"This is the University gown and hood presented to me by the great Panditji while conferring upon me the Honorary D. Sc. degree of the University. I love to preserve it for my whole life with overwhelming reverence to that mighty soul."

फिर प्रसन्न मुद्रा में उसी के भीतर से निकाल-निकालकर कई प्रकार के मणिभ (Crystals), छोटे बड़े हीरे (Diamond), चिड़ियों के अनेक रंग तथा आकार के पंख, छोटे-वड़े शंख, सीप आदि दिखाते स्फुरित होकर मोती की लर झुलाते बत्ती की रोशनी की छटा दिखाते, Asundi, look at the beauty and marvels of nature, मैं मंत्र मुग्ध था। प्रकृति की कला का गुणगान करते प्रो० रमन हम लोगों को व्याख्यानशाला में ले गये और अपनी नयी Vision theory पर भाषण देने लगे। शायद यह उनका दैनिक कार्यक्रम था वहाँ काफी संख्या में शोध छात्रों सहित अन्य लोग उपस्थित थे। भाषण में वैसी ही ओजस्विता तथा दृढ़ता पाया जैसा बहुत पहले मैंने विश्वविद्यालय में उनके कई भाषण में पाया था। एक घंटे के वाद छुट्टी मिली। हम लोगों को विदा करते उनकी मुद्रा में गम्भीरता थी और प्रो० असुडी के प्रति उनकी आन्तरिक सद्भावना एवं प्रेम की झलक अनोखी थी। उनके व्यक्तित्व की सराहना करते हम लोग वापिस गये।

प्रो० सर सी० वी० रमन सच्चे अर्थ में मनीषी और योगी थे।

रामन प्रभाव

देवेन्द्रकुमार राय
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रामन प्रभाव की खोज 1928 के फरवरी माह में कलकत्ता में सर चन्द्रशेखर वेंकट रामन तथा उनके सहकर्मियों द्वारा हुई। यद्यपि इस खोज की ऐतिहासिक तिथि 28 फरवरी 1928 ही मानी जाती है तथापि इस परिघटना का संकेत कई वर्षों पूर्व मिल चुका था। सन् 1921 में रामन ने पारदर्शक पदार्थों द्वारा प्रकाश के प्रकीर्णन पर एक व्यवस्थित शोध का श्री गणेश किया था। प्रथम दृष्ट्या तो उनका उद्देश्य लार्ड रैले द्वारा प्रतिपादित इस कथन की सत्यता की जाँच करना था' कि गहरे समुद्र में जल का जो नीला रंग दिखाई देता है वह नीले आकाश की छाया मात्र ही है।' अपने प्रयोगों द्वारा उन्होंने यह सिद्ध कर दिया कि यह कथन वास्तव में सही नहीं है और वताया कि समुद्र के जल का नीला रंग पानी के अणुओं द्वारा प्रकाश के प्रकीर्णन द्वारा उसी प्रकार उत्पन्न होता है जैसे कि आकाश का नीला रंग वायु के अणुओं द्वारा उत्पन्न होता है। इसी संदर्भ में उनका ध्यान अन्य पारदर्शक पदार्थों में प्रकाश के प्रकीर्णन की ओर गया।

प्रकीर्णित प्रकाश की तीव्रता रैले द्वारा प्रतिपादित आणविक प्रकीर्णन सिद्धान्त के अनुसार आपतित प्रकाश के तरंगदैर्ध्य के चौथे घात के व्युत्क्रमानुपाती होती है (तीव्रता $I \sim 1/\lambda^4$) अतः प्रकीर्णित प्रकाश में नीले प्रकाश की मात्रा अन्य रंगों के प्रकाश की अपेक्षा अधिक होती है अतः प्रकीर्णन के वाद प्रकाश नीला दिखाई देता है। यदि प्रकीर्णन के वाद प्रकाश को आपतित प्रकाश की दिशा के लम्ववत देखा जाय तो प्रकीर्णित प्रकाश लगभग पूर्णतया ध्रुवित पाया जाता है। ध्रुवण शत-प्रतिशत न होकर अणु के प्रकाशीय गुणों में दिशा और विन्यास के साथ जो परिवर्तन होते हैं उसके कारण कम होती है। रामन ने ध्रुवण की मात्रा में परिवर्तन का कारण अणुओं की संरचना के संदर्भ में समझा और प्रकीर्णित प्रकाश के ध्रुवण के मापन पर अनेक प्रयोग किया। इन प्रयोगों का एक महत्वपूर्ण परिणाम यह प्राप्त हुआ कि प्रकीर्णित प्रकाश के ध्रुवण की मात्रा आपतित प्रकाश के तरंगदैर्ध्य पर निर्भर करती है। इस परिणाम की सार्वभौमिकता सिद्ध करने के लिये रामन और उनके सहकर्मियों ने अनेक द्रवों पर प्रयोग किये। इन प्रयोगों के करते उन्होंने सन् 1923 में देखा कि प्रकीर्णित प्रकाश में एक अंश आपतित प्रकाश से भिन्न तरंगदैर्ध्य का उद्भाषित होता है। इस परिवर्तित तरंगदैर्ध्य के प्रकाश की उपस्थिति का

पता लगाना कोई सरल कार्य नहीं था। कारण कि प्रयोग में सौर प्रकाश का संग्रहीत पुंज उपयोग किया जाता था। प्रकीर्णित प्रकाश में इस परिवर्तित प्रकाश के अस्तित्व का सत्यापन ही कठिन था साथ ही बराबर यह संदेह बना रहता कि संभवतः यह द्रव में किसी प्रकार की अशुद्धि के कारण उत्पन्न होता है। इन अशुद्धियों को क्रमशः कम से कम करते कई वर्षों तक ऐसे अनेक प्रयोग किये गये। सन् 1925 में रामन के एक शिष्य डा० कृष्णन ने लगभग 60 अतिशुद्ध द्रवों पर प्रयोग किये। इनमें से कई द्रवों में प्रकीर्णित प्रकाश का रंग नीला न होकर हरा-पीला या नारंगी जैसा भी दिखाई पड़ा। प्रकीर्णित प्रकाश का ध्रुवण भी अपेक्षाकृत अधिक पाया गया। इस प्रकार सन् 1927 में रामन ने स्वयं ही 14 प्रकार के प्रकाशीय काँचों से प्रकाश के प्रकीर्णन का अध्ययन किया जिनमें भी उसी प्रकार के परिणाम मिले जैसे कृष्णन को मिले थे।

पहले तो रामन और उनके सहयोगी परिवर्तित तरंगदैर्ध्य वाले प्रकाश को प्रदीप्ति (**Fluorescence**) समझकर भ्रमित रहे किन्तु जब रामन का ध्यान काम्प्टन प्रभाव पर पड़ा तो वे तुरन्त ताड़ गये कि उनके प्रयोगों के परिणाम वास्तव में काँम्प्टन प्रभाव का ही प्रकाशीय अनुरूप हैं। यह झलक पाते ही उन्होंने सौर प्रकाश के स्थान पर पारे के आर्क लैम्प की विविक्त स्पेक्ट्रम रेखाओं का उपयोग किया और देखा कि प्रकीर्णित प्रकाश में आर्क की वर्णक्रमी रेखाओं के अतिरिक्त अन्य रेखायें भी प्रकट होती हैं और इन अतिरिक्त रेखाओं की तरंगदैर्ध्य प्रकीर्णक पर निर्भर करती हैं। इसी अन्वेषण का नाम रामन प्रभाव घोषित हुआ। अनेक प्रयोगों के परिणामों के आधार पर इस रामन प्रभाव के लक्षण निम्नलिखित रूप में व्यक्त किये जा सकते हैं।

1. आपतित प्रकाश की विविक्त किरणों को प्रत्येक रेखा प्रकीर्णन के पश्चात कुछ अतिरिक्त रेखाओं को उत्पन्न करती हैं जिनकी तरंगदैर्ध्य आपतित तरंगदैर्ध्य से भिन्न होती है।
2. इन रेखाओं की तीव्रता अपरिवर्तित प्रमुख रेखा की तीव्रता से बहुत ही कम होती है तथा सभी रेखाओं की तीव्रता में भिन्नता पायी जाती है।
3. इन रेखाओं के ध्रुवण की मात्रायें भी भिन्न भिन्न होती हैं।
4. इन अतिरिक्त रेखाओं की तरंग संख्या तथा आपतित प्रकाश रेखा की तरंग संख्या का अन्तर प्रकीर्णक अणु के किसी न किसी कम्पन की तरंग संख्या के बराबर होता है। (अतः रामन स्पेक्ट्रम से उसी प्रकार की जानकारी मिल सकती है जैसी कि अवरक्त स्पेक्ट्रम से) साधारणतया अणु के सभी कम्पनों के संगत अतिरिक्त रेखायें नहीं प्राप्त होतीं।
5. अतिरिक्त रेखायें आपतित प्रकाश की एक रेखा के दोनों ओर (अर्थात कम तथा अधिक दोनों प्रकार के तरंगदैर्ध्यों के संगत) पाई जाती है परन्तु कम तरंगदैर्ध्य की ओर पाई जाने वाली रेखाओं की तीव्रता उनके संगत अधिक तरंगदैर्ध्य वाली रेखाओं की अपेक्षा बहुत कम होती है।

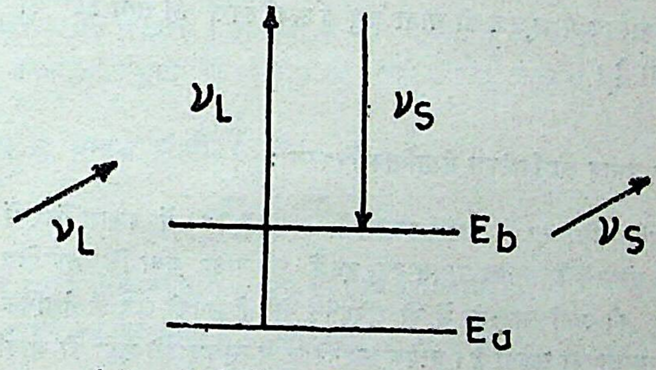
रामन प्रभाव का सैद्धान्तिक विवेचन :

(क) कांम्पटन प्रभाव के अनुरूप विवेचन:

प्रकाश के क्वाटम सिद्धान्त के अनुसार आवृति ν_L के विकिरण को $h\nu_L$ ऊर्जा वाले कण के रूप में समझा जा सकता है जिसे फोटान कहते हैं। इस प्रकार प्रत्येक आवृति की किरण के संगत फोटान की अभिकल्पना है। यहाँ h प्लाक का स्थिरांक है। ऐसा कण जब किसी अणु से टकराता है तो कण तथा अणु में ऊर्जा का आदान प्रदान हो सकता है। इस आदान प्रदान में ऊर्जा संरक्षण का सिद्धान्त लागू होता है अतः प्रकीर्णित किरण की परिवर्तित आवृत्ति ν_S के संगत (ऊर्जा $h\nu_S$) अणु की ऊर्जा में इस प्रकार परिवर्तन होता है कि निकाय (अणु + प्रकाश कण) की ऊर्जा अन्योन्य क्रिया के पूर्व तथा अन्योन्य क्रिया के वाद अपरिवर्तित वनी रहती है। इसको निम्नलिखित प्रकार व्यक्त

$$h\nu_L + M \rightleftarrows M^* + h\nu_S$$

किया जा सकता है। जिसमें M तथा M^* क्रमशः अनुत्तेजित तथा उत्तेजित अणु के द्योतक हैं। ऊर्जा के संरक्षण सिद्धान्त के अनुसार $h\nu_L - h\nu_S = E(M^*) - E(M)$ होना आवश्यक है। क्वांटम सिद्धान्त के अनुसार अणु की आंतरिक ऊर्जा भी विविक्त स्तरों में ही परिवर्तित हो सकती है अतः यह स्पष्ट है कि उत्तेजित अणु M^* और वही अनुत्तेजित अणु M अणु के किसी न किसी विविक्त ऊर्जा स्तर के संगत होंगे।



($M_a = E(M)$ तया $E_b = E(M^*)$)

(चित्र अ) : सामान्य रामन प्रभाव

संक्षेप में हम कह सकते हैं कि आपतित प्रकाश कण (फोटान) अपनी ऊर्जा का ुछ छोटा अंश अणु को देकर उसे एक उत्तेजित अवस्था में पहुँचा देता है। अतः प्रकाश कण की ऊर्जा उसी मात्रा में घट जाती है और प्रकीर्णित किरण की तरंग दैर्ध्य आपतित किरण की अपेक्षा अधिक हो जाती है। यह भी संभव है कि अन्योन्य क्रिया के पूर्व अणु किसी उत्तेजित अवस्था में हो तथा अंत में वह अपनी सामान्य अवस्था में आ जाये और इस प्रकार निसृत ऊर्जा प्रकाश कण की ऊर्जा में वृद्धि कर दे। ऐसी दशा में कीर्णित किरण की तरंगदैर्ध्य आपतित किरण की अपेक्षा कम हो जाती है। यहाँ दो

बातों पर ध्यान देना आवश्यक है। प्रथम तो यह की प्रतिदिप्ति की परिघटना से रामन प्रभाव की परिघटना भिन्न है, क्योंकि प्रतिदीप्ति के लिये यह आवश्यक है कि आपतित प्रकाश कण की ऊर्जा अणु के किसी उत्तेजित अवस्था (M^*) तथा उसकी सामान्य अवस्था (M) के ऊर्जा अन्तर के समतुल्य हो। ऐसी स्थिति में आपतित प्रकाशकण की ऊर्जा पूर्णतया अवशोषित हो जाती है तथा अणु अपनी उत्तेजित अवस्था में चला जाता है किन्तु उत्तेजित अवस्थायें अल्पायु होती है अतः उत्तेजित अणु उस अवस्था से किसी कम ऊर्जा की अवस्था में संक्रमण करता है और इस संक्रमण के फलस्वरूप एक नया प्रकाश कण उत्सर्जित होता है। अतः प्रतिदीप्ति की परिघटना का विवेचन दो स्तरों के बीच इस प्रकार किया जा सकता है।

$$h\nu + M \rightrightarrows M^*$$

$$M^* \rightrightarrows M^+ + h\nu^1$$

यदि दूसरे समीकरण में M^+ के स्थान पर M हो जाय तो ν^1 तथा ν एक समान होंगे। ऐसी प्रतिदीप्ति को अनुनादी प्रतिदिप्ति कहते हैं। दूसरा तथ्य जो इसी विवेचन से सम्बद्ध है वह यह है कि प्रतिदीप्ति परिघटना में उत्सर्जित किरण सामान्यतया ध्रुवण रहित होती है, जब कि रामन प्रभाव से प्राप्त प्रकीर्णित किरण एक सीमा तक ध्रुवित होती है। वास्तव में ध्रुवण की मात्रा अणु के ऊर्जा स्तरों M तथा M^* की प्रकृति पर निर्भर करती है।

(ख) रामन प्रभाव का विक्षेपण सैद्धान्तिक विवरण :

क्वांटम सिद्धान्त के प्रारम्भिक दिनों (1922-24) में प्रकाश किरणों की विक्षेपण प्रक्रिया को समझने के अनेक प्रयास हुये, इनमें यह माना गया कि आपतित किरण के कारण अणु की ऊर्जा अवस्था में जो परिवर्तन होते हैं उनको अणु के नैसर्गिक ऊर्जा स्तरों के पदों में समझा जा सकता है। प्रत्येक ऊर्जा स्तर से सम्बद्ध इलेक्ट्रान की आवृत्ति तथा इस ऊर्जा स्तर की मोटाई जो इसके आयु से निर्धारित होती है की सहायता से अणु में होने वाले परिवर्तन को व्यक्त किया जा सकता है। क्रेमर्स तथा हाइजेनवर्ग ने इस प्रकार का एक पूर्ण सैद्धान्तिक विवेचन प्रस्तुत किया था और जर्मन-आस्ट्रियन वैज्ञानिक स्मेकेल ने तो सन् 1924 में एक शोध पत्र प्रकाशित भी किया था जिसमें प्रकीर्णन की प्रक्रिया में प्रकाश के तरंगदैर्ध्य परिवर्तन की संभावना को व्यक्त किया गया था। बाद में डिराक ने 1927 में प्रकाश उत्सर्जन तथा अवशोषण के सभी पहलुओं पर विचार करके जो सिद्धान्त प्रतिपादित किया उसके आधार पर रामन प्रभाव को समझना सरल हुआ। इन सिद्धान्तों का वर्णन यहाँ सम्भव नहीं है क्योंकि इनके विवेचन के लिए विस्तृत गणितीय व्याख्या आवश्यक है।

(ग) रामन प्रभाव का ध्रुवण (पोलराइजेविलिटी) सिद्धान्त :

सन् 1931 में प्लेच्जेक (Placzek) ने रामन प्रभाव की एक सरल व्याख्या प्रस्तुत की जो विकिरण के अर्ध चिरसम्मत सिद्धान्त पर आधारित है। इस व्याख्या की अभिकल्पना यह है कि प्रकाश के प्रभाव से अणु में जो परिवर्तन होते हैं, उन्हें उसकी ध्रुवण (पोलराइजेविलिटी) में होने वाले परिवर्तनों से प्रतिस्थापित किया जा सकता है। हम जानते हैं कि जब किसी पदार्थ को विद्युत क्षेत्र में रखते हैं तो उसके अणुओं की धनात्मक तथा ऋणात्मक आवेशों की स्थितियाँ थोड़ी बदल जाती हैं तथा यदि अणु में कोई द्विध्रुव नहीं भी रहता है तो उसमें एक द्विध्रुव उत्प्रेरित हो जाता है। यदि विद्युत क्षेत्र की तीव्रता समय के साथ परिवर्तनशील हो तो इस द्विध्रुव का परिमाण भी समय के साथ-साथ बदलता जाता है तथा इस बदलाव की आवृत्ति वही होती है जो कि लगाये गये विद्युत क्षेत्र की होती है। यदि अणु में एक द्विध्रुव पहले से ही स्वतः विद्यमान रहता है तो भी उसके अतिरिक्त एक उत्प्रेरित द्विध्रुव उत्पन्न होता है पर इसका मान सामान्यतया नैसर्गिक द्विध्रुव के मान से अत्यल्प होता है। दोनों ही दशाओं में उत्प्रेरित द्विध्रुव आघूर्ण को आरोपित विद्युत क्षेत्र की तीव्रता के पदों में व्यक्त किया जा सकता है :

$$\vec{P} = \propto \vec{E}$$

यहाँ $\propto$ एक स्थिरांक है जो व्यापक परिस्थितियों में एक टेन्सर राशि होता है पर यहाँ हम उसके टेन्सर गुणों को ध्यान में नही रखेंगें। अतः यदि विद्युत क्षेत्र आवृत्ति ν के प्रकाश से सम्बद्ध हो तो $\vec{E}$ को

$$\vec{E} = \vec{E}o \cos 2\pi \nu t$$

के रुप में लिख सकते हैं। अणु की पालेराइजेबिलिटी $\propto$ का मान उसके कंपन या धूर्णन के कारण बदलता रहता है। अतः उसे

$$\propto = \propto_0 + \propto_{vib} \cos 2\pi \nu_{vib} t$$

अथवा

$$\propto = \propto_0 + \propto_{rot} \cos 2\pi (2 \nu_{rot}) t$$

के रूप में लिख सकते हैं। यहाँ ν_{vib} तथा ν_{rot} क्रमशः अणु के कंपन तथा घूर्णन की आवृत्ति है। $\vec{E}$ तथा $\propto$ के इन मानो को $\vec{P}$ के व्यंजक में रखने पर हमें

$$\vec{P} = \propto_0 \vec{E}o \cos 2\pi \nu t + \propto_{vib} \vec{E}o \cos 2\pi \nu_{vib} t \cos 2\pi \nu t$$

तथा

$$\vec{P} = \alpha_0 \vec{Eo} \cos 2\pi \nu t + \alpha_{rot} \vec{Eo} \cos 2\pi (2\nu_{rot})t \ \cos \ 2\pi \nu t$$

प्राप्त होता है। इस प्रकार हम देखते हैं कि द्विध्रुव आघूर्ण $\vec{P}$ के कंपन ν, $\nu \pm \nu_{vib}$, ($\nu \pm 2\nu_{rot}$) इन तीन आवृत्तियों के हो सकते हैं। चूँकि चिरसम्मत सिद्धान्त के अनुसार किसी आवेशित कंपनी द्विध्रुव से विद्युत चुम्वकीय तरंगे उत्सर्जित होती है जिनकी आवृत्ति कम्पन आवृत्ति के ही समान होती है अतः तीन आवृत्तियों के प्रकाश उत्सर्जित हो सकते हैं। इनमें ν आवृत्ति रैले रेखा (अपरिवर्तित तरंगदैर्ध्य) के संगत, $\nu - \nu_{vib}$ ($\nu - 2\nu_{rot}$) स्टोक्स रेखा के संगत (दीर्घ तरंगदैर्ध्य) तथा $\nu + \nu_{vib}$ $(\nu + 2\nu_{rot})$ प्रतिस्टोक्स रेखा (लघु तरंगदैर्ध्य) के संगत हैं। स्टोक्स तथा प्रति स्टोक्स रेखाओं की तीव्रता $/ \alpha_{vib}\ Eo/^2$ ($1\ \nu_{rot}\ \ Eo1^2$) के समानुपाती होती है जब कि रैले रेखा की तीव्रता $/ \ \alpha_0\ Eo\ /^2$ के समानुपाती है। अतः स्पष्ट है इनकी तीव्रता रैले रेखा की अपेक्षा क्षीण होंगी। इस सिद्धान्त के अनुसार स्टोक्स तथा संगत प्रतिस्टोक्स दोनों ही रेखाओं की तीव्रता समान होनी चाहिये। किन्तु प्रायोगिक मापन से उनकी तीव्रता का मान भिन्न पाया जाता है। साथ ही इस सिद्धान्त के अनुसार यह भी नहीं ज्ञात होता कि उनमें विविक्त रेखाएँ कैसे प्रकट हो जाती हैं। अतः हमें मानना पड़ता है कि $\nu \pm \nu_{vib}$ ($\nu \pm 2\ \nu_{rot}$) की प्रकाश आवृत्ति के संगत प्रकाश कण की ऊर्जा $h(\nu \pm \nu_{vib})$ $[h\ (\nu \pm 2\ \nu_{rot}\ )\ ]$ है और अणु की ऊर्जा में परिवर्तन $h\ \nu_{vib}$ ($2h\ \nu_{rot}$) तथा $-h2\nu_{vib}$ ($-\ h2\nu_{rot}$) होता है। क्वांटम सिद्धान्त के अनुसार $h\ \nu_{vib}$ ($h\nu_{rot}$) के मान कुछ विविक्त मानों तक ही सीमित रहते हैं।

यदि हम इस अर्ध चिर सम्मत सिद्धान्त को परिवर्धित और परिमार्जित करना चाहें तो हमें क्वांटम यांत्रिक विवेचन की ही भांति जटिल गणित का सहारा लेना पड़ता है। अतः हम उस पर यहाँ ध्यान नहीं देगे। एक तथ्य की ओर संकेत किया जा सकता है कि चिरसम्मत सिद्धान्त के अनुसार भी सम्बन्ध $\vec{P} = \alpha \vec{E}$ केवल सन्निकटतः ही सत्य है। प्रवल वैद्युत क्षेत्रों में इसके स्थान पर

$$\vec{P} = \alpha \ \vec{E} + \beta \ \vec{E}\ \vec{E} + \cdots$$

का उपयोग आवश्यक होता है। इस प्रकार के तीव्र प्रकाशीय विद्युत क्षेत्र लेसर के आविष्कार के वाद संभव हो सके हैं। यदि इस प्रकार के लेसर का उपयोग किया जाय तो हम सहज ही देख सकते हैं कि $\vec{P}$ के मान में कुछ अन्य आवृत्तियाँ जैसे $2\nu \pm \nu_{vib}$ तथा $2\nu \pm 2\nu_{rot}$ और उनके संगत की रेखायें पायी जा सकती हैं। ऐसी रामन रेखायें सर्वप्रथम 1965 में देखी गई हैं। इसे हाइपर रामन प्रभाव कहते हैं।

रामन प्रभाव के लिये आवश्यक प्रायोगिक उपकरण तथा विधियाँ :

रामन प्रभाव में उत्पन्न रेखाओं की तीव्रता बहुत क्षीण होती है। स्पष्ट ही किसी पदार्थ के रामन स्पेक्ट्रम के अध्ययन के लिए अत्यन्त ही तीव्र प्रकाश का श्रोत आवश्यक होगा। साथ ही यह भी देखा गया है कि रामन रेखाओं की तीव्रता आपतित प्रकाश के तरंग दैर्ध्य के घटने के साथ तरंगदैर्ध्य के चतुर्थघात के अनुपात में बढ़ती है। इनकी तीव्रता कम होने के कारण प्रयोगों में प्रयुक्त स्पेक्ट्रोग्राफ की दक्षता भी उत्कृष्ट होनी चाहिए। इन सभी आवश्यकताओं की जानकारी रामन प्रभाव के प्रारम्भिक प्रयोगों में ही हो गयी थी। रामन ने अपने प्रथम प्रयोगों में दूरवीन के बड़े लेंस से संघनित सौर प्रकाश का उपयोग किया था। एक वर्णता के लिए उन्होंने उपयुक्त फिल्टरों का उपयोग किया था। इन फिल्टरों से पारगमित प्रकाश की तीव्रता कम होने के साथ ही इसका तरंगदैर्ध्य परास भी अधिक होता था जिस कारण स्पेक्ट्रम अधिक स्पष्ट नहीं प्राप्त होता था। प्राय: रामन रेखाओं पर एक अविछिन्न स्पेक्ट्रम अध्यारोपित रहता था जिससे उनके मापन में कठिनाइयाँ आती थी। स्पष्ट स्पेक्ट्रम प्राप्त करने के लिए हिल्जर कंपनी द्वारा निर्मित स्थायी विचलन स्पेक्ट्रोग्राफ उपयुक्त पाया गया। इसकी प्रकाश ग्रहण क्षमता पर्याप्त होने के साथ ही इसका विक्षेपण तथा विभेदन भी आवश्यकतानुकूल पाया जाता है। बाद में दृश्य स्पेक्ट्रमी क्षेत्र में भी पारे का आर्क प्रकाश श्रोत के लिए प्रयुक्त किया गया था। इस आर्क में नीले रंग की 4358A^0 तरंगदैर्ध्य की एक तीव्र स्पेक्ट्रमी रेखा पाई जाती है। यह लघु तरंगदैर्ध्य की रेखा अपनी अधिक तीव्रता के कारण रामन प्रभाव के प्रयोगों के अत्यन्त उपयुक्त पाई गयी। पारे की आर्क की परावैंगनी रेखायें 2537A^0 और 1849A^0 भी इसी के समान उपयुक्त होती है परन्तु इनके साथ कुछ कठिनाइयाँ भी होती हैं। जिनके कारण इनका उपयोग केवल कुछ ठोस पदार्थों के प्रकीर्णन में ही किया गया। इन कठिनाइयों में से एक तो यह होती है कि इन रेखाओं के निस्सरण के लिए आर्क को क्वार्ट्ज का बना होना आवश्यक है, साथ ही छोटी तरंगदैर्ध्य के कारण इन रश्मियों से सम्बद्ध ऊर्जा मान इतने अधिक हैं कि अनेक पदार्थों में ये प्रकाश रासायनिक क्रिया उत्पन्न कर देती हैं। कुछ पदार्थों का तो प्रकाश वियोजन तक हो सकता है।

प्रकाश श्रोत तथा स्पेक्ट्रोग्राफ के अतिरिक्त प्रकीर्णक पदार्थ को रखने की व्यवस्था तथा क्वार्ट्ज लेंस द्वारा आपतित प्रकाश को संगृहीत कर उसे उद्भासित करने तथा प्रकीर्णित प्रकाश को क्वार्ट्ज लेन्स से संगृहीत करके स्पेक्ट्रोग्राफ की स्लिट पर डालने की व्यवस्था भी महत्वपूर्ण होती है। पदार्थ के रखने की व्यवस्था इस प्रकार की होनी चाहिए कि आपतित प्रकाश तथा अन्य किसी भी प्रकार का परावर्तित या विस्तरित प्रकाश संग्रहण क्षेत्र में न पहुँचे अन्यथा मद्धिम रामन रेखाओं का छायांकन दुर्लभ हो जायेगा। इसलिए रामन की प्रयोग कक्ष की दीवालें काली कर उसके भीतर स्पेक्ट्रोग्राफ सहित सारे उपकरण को एक अंधकूप-बड़े लकड़ी के बाक्स—के भीतर रखे गये थे। इस बाक्स की भीतरी तथा

वाहरी दीवालों पर काला पेन्ट पोता गया था। गैसों के रामन प्रभाव के अध्ययन अपेक्षाकृत और भी कठिन होते हैं क्योंकि इनमें प्रकीर्णक अणुओं का घनत्व कम होता है।

इन सब प्रायोगिक कठिनाइयों के कारण रामन प्रभाव के अध्ययन सन् 1940 से 1960 के वर्षों में अपेक्षाकृत कम हुए। सन् 1928 से 1940 तक के वर्षों में अधिकतर द्रवों और ठोस पदार्थों में रामन स्पेक्ट्रम का अध्ययन किया गया। गैसों पर ये प्रयोग वहुत ही सीमित रहे। द्वितीय विश्वयुद्ध के वर्षों में जो इलेक्ट्रानिक्स की प्रगति हुई उससे अवरक्त क्षेत्र में स्पेक्ट्रम का अध्ययन अपेक्षाकृत आसान हो गया था, और रामन प्रभाव के अध्ययन की गति 1960 तक मंद रहीं।

सन् 1960 के वर्ष में माइमन (Maiman) ने सर्वप्रथम रूबी लेसर का आविष्कार किया। उसी वर्ष जावान (Javan) और उनके सहयोगियों ने हीलियम-नियान लेसर का अविष्कार किया। इन लेसर श्रोतों से रामन प्रभाव के अध्ययन में एक क्रान्ति आ गई। लेसर प्रकाश की तीव्रता एवं उसकी एक वर्णता इतनी उच्च कोटि की होती है कि इसके द्वारा रामन प्रभाव को अंकित करना अत्यन्त सुलभ एवं सुगम हो गया। इसके वाद के वर्षों में जो नवीन एवं तीव्रतर लेसर श्रोतों के आविष्कार में क्रान्तिकारी परिवर्तन हुए, उनसे रामन प्रभाव का अध्ययन इतना अधिक प्रभावित हुआ है कि विज्ञान के सभी क्षेत्रों में इसका उपयोग दिनोंदिन वढ़ता ही जा रहा है। प्रोफेसर रामन ने नोवुल पुरस्कार प्राप्त करने के वाद जो भाषण दिया था उसमें कहा था :

"इस परिघटना की सार्वभौमिकता इसके लिए आवश्यक प्रायोगिक विधियों की सहजता तथा प्राप्त स्पेक्ट्रम की सरलता, इस प्रभाव को भौतिकी तथा रसायन की अनेक समस्याओं के समाधान के लिए उपयुक्त बनाते हैं। वास्तव में यह कहा जा सकता है कि यही तथ्य इस प्रभाव का मुख्य महत्त्व है। वर्णक्रम से प्राप्त आवृति-अंतर, वर्णक्रम में उपस्थित रेखाओं की मोटाई तथा प्रकृति, तथा प्रकीर्णित प्रकाश की तीव्रता एवं ध्रुवण की स्थिति, प्रकीर्णक पदार्थ की मूल संरचना में झाँकने का हमें अवसर प्रदान करती है"।

इस कथन का महत्व जितना सन् 1930 में मान्य था आज उससे कहीं सहस्त्र गुना अधिक माना जा सकता है।

लेसर के उपयोग से आविष्कृत नवीन रामन प्रभाव :

रामन प्रभाव के अध्ययन में लेसर का उपयोग निम्नलिखित प्रकार से अधिक उपयोगी पाया जाता है।

(1) लेसर प्रकाश की एक वर्णता के कारण अन्य श्रोतों के साथ पाये जाने वाले वहु उत्तेजन उपस्थित नहीं रहते और रामन स्पेक्ट्रम अपेक्षाकृत सरल पाया जाता है। साथ ही लेसर की तीव्रता के कारण स्पेक्ट्रम सरलतापूर्वक और कम समय में अंकित किये जा सकते हैं।

(2) लेसर प्रकाश का अनुप्रस्थ परिक्षेत्र कम होता है अतः प्रकोर्णक पदार्थ की कम से कम मात्रा से भी रामन स्पेक्ट्रम प्राप्त किया जा सकता है। साथ ही चूँकि लेसर प्रकाश बहुधा ध्रुवित होता है अतः रामन रेखाओं के ध्रुवण सम्वन्धी मापन अत्यन्त शुद्धता से किये जा सकते हैं। लेसर प्रकाश चूँकि विना फैले सीधी रेखा में गमन करता है अतः प्रकाश श्रोत से पदार्थ की दूरी अधिक भी रखी जा सकती है। इनके कारण तापीय तथा अन्य प्रभावों को कम किया जा सकता है।

(3) लेसर प्रकाश की तीक्ष्णता अत्यधिक होती है अतः रामन रेखाओं के आकार और मोटाई के अध्ययन अधिक शुद्धता से हो सकते हैं। साथ ही रैले रेखा के पास भी रामन रेखाओं का मापन किया जा सकता है।

(4) रजक लेसरों (dye lasers) तथा अर्धचालक लेसरों (semiconductor lasers) के प्रकाश का उपयोग करके रंगीन पदार्थों का भी रामन स्पेक्ट्रम प्राप्त किया जा सकता है, जो पहले संभव नहीं था।

(5) पिकोसेकेण्ड लेसर तथा तीव्रगामी इलेक्ट्रानिक संसूचनाविधियों के विकास से अब तीव्रगामी रासायनिक अभिक्रियाओं में भी रामन प्रभाव का उपयोग संभव हो सका है। साथ ही अनेक प्रकार के अरैखिक रामन प्रभाव भी प्राप्त किये गये हैं जो प्रकीर्णक पदार्थ की संरचना और गुणों के वारे में और अधिक जानकारी देने में समर्थ है।

अव हम रामन प्रभाव के इन नवीन अनुसंधानों का संक्षिप्त विवरण देंगे।

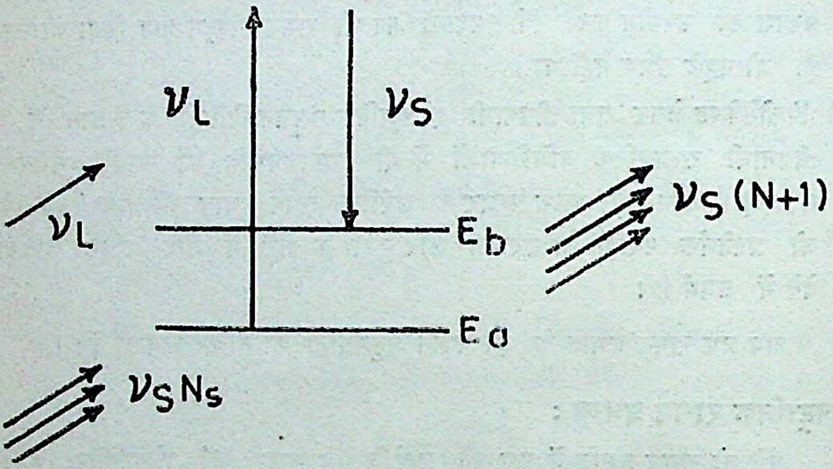
इलेक्ट्रानिक रामन प्रभाव :

वैसे तो रामन प्रभाव में अणु की उत्तेजित अवस्था M^* इलेक्ट्रानिक, कम्पनी अथवा घूर्णनी किसी भी प्रकार की ऊर्जा अवस्था हो सकती है परन्तु सामान्यतया रामन प्रभाव में यह उत्तेजना कंपन अथवा घूर्णन से ही सम्वद्ध होती है। सन् 1930 में इटालियन वैज्ञानिक रसेटी (Rasetti) ने NO अणु के रामन प्रभाव में एक प्रतिस्टोक्स रामन रेखा प्राप्त की थी जो कि इस अणु के सामान्य इलेक्ट्रानिक अवस्था $^2\pi$ के ऊपरी Λ घटक में उत्तेजित होने के संगत थी। परन्तु यह उत्तेजित अवस्था सामान्य से केवल $122\ \text{cm}^{-1}$ ऊपर होती है।

यद्यपि इलेक्ट्रानिक रामन प्रभाव की प्रथम (रसेटी के अतिरिक्त) रिपोर्ट जो $PrCl_3$ के मणिभ में Pr^{3+} आयनों की इलेक्ट्रानिक अवस्थाओं से सम्वद्ध थी हाउगेन तथा सिंह (Hougen & Singh) द्वारा 1964 में सामान्य पारे के आर्क द्वारा प्राप्त की गई थी, इनका छायांकन लेसर के उपयोग से अत्यन्त सुलभ पाया गया। 1966 में He - Ne गैस लेसर के उपयोग से Y गारनेटो में Yb, Eu तथा Nd के आयनों के इलेक्ट्रानिक रामन प्रभाव का अध्ययन संभव हो सका। इसी प्रकार GaP में Zn तथा Mg अशुद्धियों का इलेक्ट्रानिक रामन प्रभाव भी देखा गया।

उत्प्रेरित रामन प्रभावः

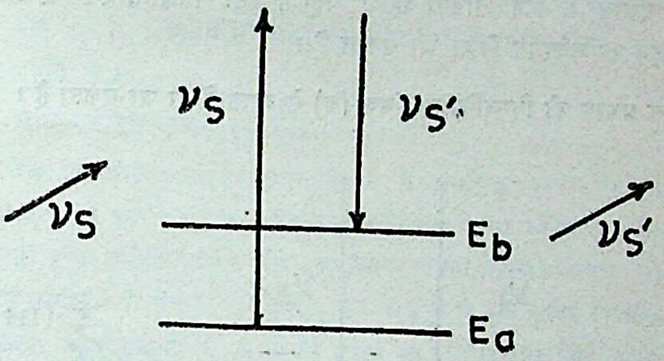
सन् 1963 में उडवरी (Woodbury) जो अपने सहयोगियों सहित नाइट्रोबेन्जीन के रामन प्रभाव का अध्ययन कर रहे थे ने एक अनोखी परिघटना देखी। उन्होंने पाया कि जव नाइट्रोवेन्जीन के सेल में रुवी लेसर का एक Q—स्विच स्पंद केन्द्रित किया जाता है तो उसमें से कला संबद्ध प्रकाश निकलता है। इस प्रकाश की तरंगदैर्ध्य इस प्रकार की है कि उसकी प्रकाश कण ऊर्जा का मान रुवी लेसर की प्रकाश कण ऊर्जा के मान से 1344 cm^{-1} कम है। यह तरंग संख्या नाइट्रोवेन्जीन के एक सममित कंपन के संगत है जिससे सामान्य रामन प्रभाव में एक उच्चतीव्रता की रेखा उत्पन्न होती है। इस स्टोक्स रेखा के उत्सर्जन को उत्प्रेरित रामन प्रभाव का नाम दिया गया।



चित्र (ब) : प्रत्प्रेरित रमन प्रभाव

इस प्रभाव को समझने के लिए हम नीचे दिये चित्रों पर विचार करेंगे। पहले चित्र (अ) में दिखाया गया है कि ν_L आवृत्ति का एक फोटान किसी अणु निकाय पर आपतित है। इसकी अन्योन्य क्रिया के कारण आणविक निकाय अपनी ऊर्जा स्थिति E_a से E_b में चला जाता है तथा ν_S आवृत्ति एक का स्टोक्स फोटान उत्सर्जित होता है। यह सामान्य रामन प्रभाव है। अब यदि आपतित प्रकाश की तीव्रता इतनी अधिक बढ़ा दी जाय कि ν_L की अन्योन्य क्रिया के कारण ν_S आवृत्ति वाले स्टोक्स फोटानों की संख्या में वृद्धि हो सके तो हमें उत्प्रेरित रामन प्रभाव (चित्र (ब))मिलेगा। वास्तव में यदि N_L , आपतित फोटानों की संख्या तथा N_S स्टोक्स फोटानों को संख्या हो तो सामान्यतया N_S का मान N_L के समानुपाती होता है परन्तु उत्प्रेरित रामन प्रभाव की दशा में N_S का मान N_L के अलावा N_S पर भी निर्भर करने लगता है और इसी कारण N_S का मान N_L के समानुपाती न होकर $N_L{}^2$ के समानुपाती हो जाता है। वास्तव में ऐसा होने के लिए आवश्यक है कि ν_S आवृत्ति वाले फोटानों की संख्या का पकीर्णक सेल में होने वाला ह्रास उनकी संख्या में ν_L के कारण होने वाली वृद्धि से कम हो। यह सामान्यतया एकाध्र

कंपनों के लिए ही सम्भव हो पाता है। अतः इस प्रभाव द्वारा रामन स्पेक्ट्रम प्राप्त करना संभव नहीं हैं। परन्तु चूँकि यह स्टोक्स प्रकाश कलासम्बद्ध है अतः इस प्रभाव का उपयोग परिवर्तित आवृत्ति पर कला सम्वद्ध प्रकाश उत्पन्न करने में किया जा सकता है। कभी कभी आपतित प्रकाश की तीव्रता अत्यधिक होने पर इन स्टोक्स तथा प्रतिस्ट्रोक्स अंतरालों के ठीक दूने, तीन गुने इत्यादि अंतरालों पर भी स्टोक्स (प्रति स्टोक्स) रेखायें प्राप्त होती है। इनकी उत्पत्ति में आपतित फोटान द्वारा उत्पन्न स्टोक्स (प्रति स्टोक्स) फोटान ही आपतित फोटान (चित्र (स)) का कार्य करने लगते हैं अर्थात $\nu'_L = \nu_S$ अतः इससे उत्पन्न स्टोक्स फोटान की आवृत्ति $\nu'_S = \nu_S - (E_b - E_a)$ होती है। इस प्रकार के स्टोक्स विकिरण कुछ विशिष्ट दिशाओं में ही उत्सर्जित होते हैं।



$$\nu'_S = \nu_S - (E_b - E_a)$$
$$= \nu_L - 2(E_b - E_a)$$

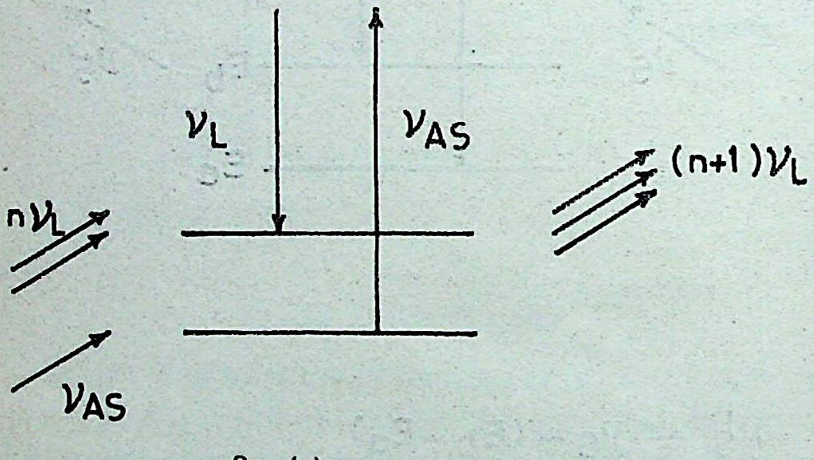
चित्र (स) : द्वितीय कोटि की स्टोक्स रेखा की उत्पत्ति

व्युत्क्रम रामन प्रभावः

यह प्रभाव सर्वप्रथम जोन्स तथा स्टाइशेफ (Jones and Stoicheff) द्वारा सन् 1964 में पाया गया था। उन्होंने वेन्जीन द्रव को एक साथ दो विकिरणों से उद्भासित किया। प्रथम तो एक एकवर्णी लेसर विकिरण या जिसकी तीव्रता उत्प्रेरित रामन प्रभाव उत्पन्न होने की तीव्रता देहली से कम थी तथा दूसरा प्रकाश एक अविच्छिन्न

स्पेक्ट्रम विकिरण (Continuous Spectrum radiation) था जिसकी तीव्रता अधिक होने के साथ ही साथ जिसका तरंगदैर्ध्य परास ऐसा था कि बेन्जीन की प्रथम एकवर्णी विकिरण से उत्तेजित प्रति स्टोक्स रामन रेखा का तरंगदैर्ध्य उसी के बीच में था। दूसरे शब्दों में यदि एक वर्णी विकिरण की आवृत्ति ν_L थी तथा इसके संगत बेन्जीन के किसी एक प्रति स्टोक्स रेखा की आवृत्ति ν_{AS} थी तो अविच्छिन्न स्पेक्ट्रम विकिरण का आवृत्ति—परास ऐसा था कि ν_{AS} उस परास के भीतर हो। जोन्स और स्टाइशेफ के प्रयोग में यह अविच्छिन्न प्रकाश टाल्यून के उत्प्रेरित रामन प्रभाव में प्राप्त एक अधिक मोटी प्रतिस्टोक्स रेखा से सम्बन्ध विकिरण था। उन्होंने पाया कि जब यह अविच्छिन्न विकिरण बेन्जीन सेल से बाहर निकलता है तो इसके स्पेक्ट्रम में ν_{AS} के स्थान पर एक तीक्ष्ण अवशोषण रेखा दिखाई पड़ती है। इसी प्रकार की अवशोषण रेखायें अन्य पदार्थों में भी प्राप्त की गई है। चूँकि इस प्रभाव में कोई तीव्रता देहली नहीं है अतः सिद्धान्त रूप से इस प्रकार पूरे रामन स्पेक्ट्रम का अध्ययन किया जा सकता है।

इस प्रभाव को निम्नलिथित चित्र (द) से व्यक्त किया जा सकता है।



चित्र (द) : व्युत्क्रम रामन प्रभाव

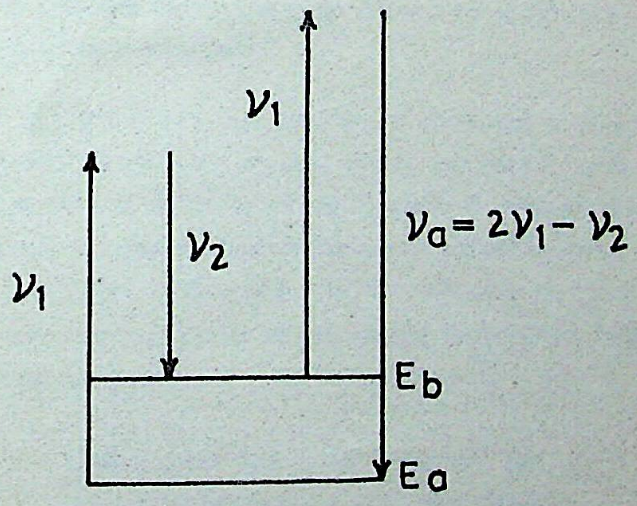
अनुनादी रामन प्रभावः

इस बात का पहले ही संकेत दिया जा चुका है कि रामन रेखाओं की तीव्रता आपतित विकिरण की तरंगदैर्ध्य के घटने के साथ तरंगदैर्ध्य के चतुर्थघात के अनुरूप बढ़ती है। सन् 1935 में क्वार्टज के रामन प्रभाव के अध्ययन के दौरान ओर्नस्टाईन (Ornstein) तथा वेंट (Went) ने पाया कि परावैंगनी विकिरण के उपयोग से क्वार्टज की कुछ रामन रेखाओं की तीव्रता में अपेक्षाकृत अधिक वृद्धि होती है। इस तथ्य को समझने के लिए उन्होंने कहा कि जब आपतित विकिरण की क्वांटम ऊर्जा प्रकीर्णक के किसी

अवशोपण बैंड की ऊर्जा से बराबर हो जाती है तो प्लेक्जेक का सैद्धान्तिक विवेचन सही नहीं रह पाता। इस विवेचन को अनेक वैज्ञानिकों ने परिवर्धित किया है जिससे कि ऐसी परिस्थितियों में प्राप्त रामन स्पेक्ट्रम की व्याख्या की जा सके। प्रायोगिक दृष्टि से इस तीव्रता वृद्धि का महत्व अत्यधिक है क्योंकि रामन प्रभाव की सबसे बड़ी कमी रामन रेखाओं की क्षीणता ही रही है। इसी कमी के कारण विश्लेषण अनुपयोगों में इस प्रभाव का उपयोग अवशोषण तथा प्रतिदीप्ति पर आधारित विधियों की अपेक्षा कम हो पाता था। अत्यधिक तीव्र तथा एक वर्णी लेसर विकिरण के उपयोग तथा रंजक लेसरों द्वारा विस्तृत क्षेत्र पर इस प्रकार का प्रकाश उत्पन्न करने की क्षमता के विकाश के कारण अनुनादी रामन प्रभाव के उपयोग में हाल के वर्षों में अत्यधिक वृद्धि हुई है। चूँकि इस प्रकार प्राप्त स्पेक्ट्रम में रामन रेखाओं की तीव्रता, मोटाई तथा अन्य परिवर्तन उस इलेक्ट्रानिक अवस्था द्वारा निर्गमित होते हैं जिनके अवशोपण बैंड से आपतित विकिरण की आवृत्ति मेल खाती है अतः इनके अध्ययन से आणविक संरचना में होने वाले परिवर्तनों का अध्ययन सम्भव होता है।

कलासम्बद्ध प्रति स्टोक्स रामन स्पेक्ट्रमः

हमने देखा कि यद्यपि उत्प्रेरित रामन प्रभाव में उत्सर्जित रामन रेखा की तीव्रता अत्यधिक होती है परन्तु इस प्रभाव की सहायता से किसी पदार्थ का रामन स्पेक्ट्रम प्राप्त करना संभव नहीं होता क्योंकि इसके लिये आवश्यक तीव्रता देहली प्रतिबंध सभी रामन रेखाओं के लिए सामान्यतया संतुष्ट नहीं होते। हाल के वर्षों में एक नवीन विधि-कला संवद्ध प्रतिस्टोक्स रामन स्पेक्ट्रोस्कोपी (C A R S) (चित्र क) का विकास किया गया है जिसमें इस प्रतिवन्ध को संतुष्ट करने की आवश्यकता नहीं रहती और साथ ही रामन रेखाओं की तीव्रता उत्प्रेरित रामन प्रभाव की ही भांति अधिक बनी रहती है।



चित्र (क) : कला संवद्ध प्रतिस्टोक्स रामन वर्णक्रम की प्राप्ति का सिद्धान्त

इस विधि में रामन प्रकीर्णक दो-दो आवृत्तियों के एक वर्णी विकिरणों से एकसाथ उद्भासित किया जाता है। इन आवृत्तियों ν_1 तथा ν_2 का चुनाव इस प्रकार किया जाता है कि $\nu_1 - \nu_2$ प्रकीर्णक के किसी विशेष कंपन आवृत्ति ν_{vib} के बराबर हो। इस दशा में ν_1 द्वारा जो अणु सामान्य स्तर से उत्तेजित होते हैं वे ν_2 द्वारा उत्प्रेरित होकर अणु के ऊपरी ऊर्जा स्तर E_b पर जाते हैं। वहां पर वे अणु ν_1 द्वारा पुनः उत्तेजित होते हैं और फिर सामान्य स्तर E_a पर आते हैं और इस क्रिया में $2\nu_1 - \nu_2$ पर एक प्रतिस्टोक्स विकिरण उत्पन्न करते हैं। इस प्रकार के विकिरण के लिये कुछ विशेष प्रतिबन्धों को पूरा करना होता है। गैसीय पदार्थों के लिए यदि ν_1 तथा ν_2 दोनों दृश्य क्षेत्र में हो तो ये प्रतिबन्ध दोनों विकिरणों को एक ही दिशा में प्रगामित करके संतुष्ट किये जा सकते हैं। द्रव तथा ठोस पदार्थों में इन्हें सन्तुष्ट करना अधिक कठिन पाया जाता है। इस विधि का उपयोग भी इधर के वर्षों में तेजी से बढ़ा है।

श्यामल धवल हिलोरें

देवेन्द्र शर्मा

भूतपूर्व कुलपति, इन्दौर विश्वविद्यालय

> 'खिला हुआ नगण्यतम फूल मेरे अन्दर उन विचारों को जगा सकता है जिनकी गहराई की थाह पाना अक्सर ही अत्यन्त दुष्कर है।'*
>
> —वर्ड्सवर्थ

वह वैज्ञानिक जिसके शोध कार्य को प्रकृति के सौंदर्य ने प्रेरित किया वह था भारतरत्न चन्द्रशेखर वेंकट रामन जिसका जन्म शताब्दी वर्ष चल रहा है।

प्रोफेसर रामन के नाम के साथ बचपन से ही मेरे मस्तिष्क में एक ओजस्वी व्यक्तित्व की कल्पना बनी हुई थी। आज से लगभग पैंतालिस वर्ष पूर्व जब शीत ऋतु की एक सुबह इलाहाबाद में उनसे साक्षात्कार हुआ तो उस महान् वैज्ञानिक के साथ जुड़े प्रभामण्डल और सम्भ्रान्त व्यक्तित्व के सामने कुछ क्षण के लिए संकोच हुआ, परन्तु उनकी सहृदयता और विनोदी स्वभाव से प्रभावित होकर मैंने कुछ शङ्काओं का समाधान करने की धृष्टता की। इनमें डिबाई का सिद्धान्त भी था जिससे वे न केवल पूर्णतया असहमत थे वरन् उसे नापसन्द भी करते थे। उस समय मैंने जो प्रश्न किए शायद अधिक परिपक्व होने पर नहीं करता। अब मुझे आश्चर्य होता है कि प्रोफेसर रामन ने बड़ी सहज आत्मीयता के साथ मेरी शङ्काओं का समाधान किया।

जहाँ आज बहुत से युवक विश्वविद्यालयों और शोधसंस्थानों के विद्योचित पदों को छोड़कर प्रशासनिक सेवाओं में जाने को आतुर रहते हैं, वहीं रामन ने भारत सरकार के वित्त विभाग में उच्च पद को छोड़कर 29 वर्ष की अवस्था में कलकत्ता विश्वविद्यालय के तत्कालीन कुलपति सर आशुतोष मुखर्जी के निमन्त्रण पर भौतिकी के पालित आचार्य का पद स्वीकार किया, जिससे उनकी शोध के प्रति निष्ठा और रुचि को फलने-फूलने का अवसर मिल सके। बमुश्किल 18 वर्ष की आयु होते-होते फ़िलोसोफ़ीकल मैगज़ीन में उनका प्रथम शोध-प्रबन्ध छप चुका था।

'टु मी द मीनेस्ट फ्लावर दैट ब्लोज कैन गिव,
थौट्स दैट डू ऑफन लाइ टू डीप फ़ॉर टिअर्स,'

—वर्ड्सवर्थ

वैज्ञानिक सही अर्थों में कलाकार होता है। रामन के सौन्दर्य बोध और सुरुचि का प्रभाव न केवल उनके दैनिक जीवन पर पड़ा. वरन् उनके शोध में भी वह स्पष्ट परलक्षित होता है। संगीत के प्रेम ने उन्हें वाद्ययन्त्रों के भौतिकीय सिद्धान्त प्रतिष्ठित करने की प्रेरणा दी। उधर भूमध्य सागर की 'देखत स्यामल धवल हिलोरें' प्रकाश के प्रकीर्णन में उनकी रुचि जगी, जिसकी परिणति उस शोध में हुई जो आज रामन प्रभाव के नाम से जाना जाता है और जिसमें लेसरों के आविष्कार के साथ तेजी से नई दिलचस्पी पुनः जागृत हुई है। शीर्षस्थ वैज्ञानिकों ने इस शोध का स्वागत करते हुए कहा था कि प्रकाश के क्वाण्टम सिद्धान्त का यह सबसे विश्वसनीय प्रमाण है। आइन्स्टाइन ने अपने उद्गार इन शब्दों में व्यक्त किए, 'पदार्थ के सानिध्य में फ़ोटोन की ऊर्जा में आंशिक परिवर्तन हो सकता है इस बात को रामन ने पहचाना और प्रदर्शित किया।' इस प्रभाव के महत्व का अनुमान इस बात से लगाया जा सकता है कि 1928 में इसके अन्वेषण के अपेक्षाकृत कम समय बाद 1930 में ही रामन को नोबल पुरस्कार से सम्मानित किया गया।

रामन प्रभाव की सरलता और ऐसे उपकरणों द्वारा उसका शोध जो उस समय के विश्वविद्यालयों तथा शोध संस्थानों की प्रयोगशालाओं में सामान्यतः उपलब्ध थे विशेष महत्व की बात है। रामन के सभी शोध भारतीय परिवेश में हुए जिससे उनकी प्रतिभा के अतिरिक्त उनका उत्कट देश-प्रेम स्पष्ट होता है। परमाणु और क्रिस्टल संरचना तथा रासायनिक अभिनिर्धारण के अतिरिक्त विशेष सममितियों के अणुओं के घूर्णन रामन स्पेक्ट्रम के अध्ययन द्वारा न्यूक्लीय स्पिन तथा सांख्यिकी जैसी मौलिक जानकारी प्राप्त करने में रामन प्रभाव का विशेष महत्व है।

रामन की अद्वितीय प्रतिभा का अनुमान पराश्रव्य तरंगों द्वारा प्रकाश के विवर्तन के नगेन्द्र नाथ के साथ उनके सिद्धान्त के सम्बन्ध में मैक्स बोर्न के इन शब्दों से लगाया जा सकता है, 'रामन की कुशाग्र बुद्धि गणित के ऊपर फाँद जाती है।'

परमाणुओं (इलेक्ट्रॉन-मेघ) द्वारा एक्सकिरणों के प्रकीर्णन का सिद्धान्त रामन द्वारा प्रतिपादन के कुछ समय बाद कॉम्प्टन ने भी स्वतंत्र रूप से दिया था परन्तु यह महत्वपूर्ण है कि कॉम्प्टन ने अपने प्रतिष्ठित ग्रन्थ में रामन का निरूपण (प्रतिपादन) दिया है।

जिन लोगों ने रामन के व्याख्यान सुने हैं (कक्षा में छात्र के नाते या अन्यथा) वे जानते हैं कि रामन में गूढ़ तत्वों को जीवन के सामान्य अनुभवों, रोज़मर्रा के परिदृश्यों, उदाहरणों तथा आख्यानों के साथ अत्यन्त सरल और रोचक ढंग से प्रस्तुत करने की अपूर्व क्षमता थी। उनका उत्साह विषय को समझने में उत्प्रेरक का कार्य करता था। वे कहते थे कि जिन तथ्यों को सुगमता से नहीं समझाया जा सकता उनके जानने का महत्व नहीं रहता।

यद्यपि सतही दृष्टि से भिन्न, आधुनिक भारत के दो युग पुरुषों, गाँधी और रामन, में एक गहरी समानता थी। अगाध देश-भक्ति, देश के गौरव और आत्म सम्मान में आस्था, अहिंसा में विश्वास और युद्ध से घृणा दोनों को एक तल पर रखते थे। दोनों ही उच्च विचारक और महान् प्रयोगकर्त्ता थे, सब तरह से सतर्क और सावधान। साथ ही उनमें गूढ़ विचारों और सिद्धान्तों को श्रोताओं तक प्रभावी ढंग से पहुँचाने की ऐसी क्षमता थी कि वे उन्हें आत्मसात् करके उन पर आचरण करने लगे। इसके अतिरिक्त दोनों में अद्‌भुत विनोद प्रियता थी जिससे वे अपने सम्भ्रान्त प्रभामण्डल के बावजूद व्यक्ति को अपनी ओर आकर्षित करके उसे सहजता का अनुभव करा देते थे। इस संदर्भ में प्रोफेसर रामन द्वारा सुनाई एक घटना याद आती है। अकस्मात मिले एक स्विस जीव-वैज्ञानिक को वे महात्मा गाँधी से (जो उन दिनों बंगलूर में प्रवास पर थे) मिलाने ले गए। बातचीत के दौरान जब गाँधी जी को यह ज्ञात हुआ कि उनका अतिथि द्रव वायु ताप पर बिना भोजन रखे गये कुछ सूक्ष्म जीवों के ऊपर पड़ रहे प्रभाव का अध्ययन कर रहा है तो, प्रोफेसर रामन के शब्दों में 'महान् महात्मा' ने कहा, "तुम्हारे शोध के परिणामों में मेरी गहरी रुचि है। पूरा होने पर मुझे उनसे अवगत कराना।"

प्रोफेसर रामन के विनोद का एक और प्रसंग याद आ रहा है। एक बार उन्होंने हँसते हुए कहा कि पहले वे अपने जीवन को इतना बहुमूल्य समझते थे कि वायुयान द्वारा यात्रा करने का जोखिम नहीं उठाना चाहते थे।

अपने सिद्धान्तों के बचाव करने में रामन एक सीमा तक कट्टरता का परिचय देते थे तथा अपने सहयोगियों से वे कार्य के प्रति निष्ठा और समर्पण की अपेक्षा करते थे। साथ ही नवयुवकों को प्रोत्साहित करने तथा उनमें आत्म विश्वास जगाने में कोई कन्जूसी नहीं बरतते थे। एक बार प्रयाग विश्वविद्यालय की एक शोध-छात्रा को उसकी मौखिक परीक्षा के बाद इन शब्दों में सम्बोधित किया, "तुमने अपूर्व आत्मविश्वास के साथ अपने विचारों को स्पष्ट किया है। पहली बार जब मैं बोलने के लिए खड़ा हुआ था तब मेरी टाँगे काँप रही थीं।"

ऐसे ही एक और अवसर पर एक अन्य विषय के वरिष्ट प्रोफेसर के साथ संभवतः भौतिकी की किसी समस्या पर बात करते हुए प्रोफेसर रामन विश्वविद्यालय के भौतिकी विभाग में प्रवेश कर रहे थे तब उनको अपने साथी से सामने पड़े एक शोध छात्र की ओर इशारा करके यह कहते सुना, "आप नहीं वह मेरी बात समझेगा।" इन शब्दों को सुनकर अवश्य ही उस नवयुवक का आत्मविश्वास बहुगुणित हो गया होगा।

उनकी स्मरण शक्ति और सूक्ष्म दृष्टि पर अचरज होता था जब वे दो या तीन दिन के लिए प्रयाग आने पर भी वहाँ हो रहे शोध कार्य का संदर्भ अपने व्याख्यान को स्थानीय परिवेश में गम्य बनाने के लिए कर देते थे।

सही अर्थों में रामन महान् वैज्ञानिक के साथ एक महान मानव थे। उनकी सुरुचि और आसपास के सामान्य वातावरण / परिवेश से संगीत और 'श्यामल धवल हिलोरों' (हरित-नील दूधिया सागर तरंगों) से प्रारम्भ हुई यात्रा अनेक मोड़ों से होती हुई उनके अन्तिम दिनों में मणियों, फूलों और तितलियों के जीवन्त रंगों से मुग्ध होकर दृष्टि विज्ञान के गूढ़ रहस्यों को जानने में आगे बढ़ी—गीता में श्रीकृष्ण के शब्दों (4-38) में

'न हि ज्ञानेन सदृशं पवित्रमिह विद्यते।'

'रमन प्रभाव' और सूर्य - विज्ञान

डॉ० जनार्दन उपाध्याय
संस्कृत विद्या एवं धर्म विज्ञान संकाय,
काशी हिन्दू विश्वविद्यालय, वाराणसी-221005

श्री चन्द्रशेखर वेंकट रमन भारतीय विज्ञान के ज्योतिपुरूष हैं। इनके चिन्तन मनन की प्रकाश रश्मियों से भारतीय विज्ञान की दिशा को एक नया आयाम मिला है। सत्य तो यह है कि न केवल भारतीय विज्ञान, अपितु भौतिकी, रसायन विज्ञान को 'रमन प्रभाव' से एक नया आलोक मिला है। यों तो वैज्ञानिक खोजे हुआ करती हैं। उनका एक निश्चित दिक्-काल (Time-Space) में सापेक्षिक महत्व और प्रभाव भी रहता है। पर 'रमन-प्रभाव' की चिरकालिक सार्वभौम उपादेयता है। इसकी शाश्वत उपयोगिता को रेखांकित करते हुए स्वयं श्री चन्द्रशेखर वेंकट रमन ने सन् 1930 में नोवेल पुरस्कार ग्रहण करते समय कहा था "प्रकाश के प्रकीर्णन का यह अध्ययन हमें भौतिकी और रसायन की गहनतम समस्याओं तक ले जा सकता है·········परिघटना की सार्वभौमिकता, प्रायोगिक विधि की सरलता और वर्णक्रम (स्पेक्ट्रम) को प्राप्त करने की सहजता, इस प्रभाव को भौतिक तथा रसायन की अनेकानेक समस्याओं का समाधान प्राप्त करने वाला एक उपयोगी साधन बना देती है।"

रमन के आविष्कार का मुख्य विन्दु 'पदार्थ पर प्रकाश की खोज' था। प्रारम्भ में रमन ने सूर्य प्रकाश को स्रोत रूप में प्रयुक्त किया था। सूर्य प्रकाश का पदार्थ के संघटन और विघटन पर क्या प्रभाव पड़ता है तथा कैसे सूर्य - रश्मियों से सृष्टि का निर्माण होता हैं, यह एक रहस्य है। भारतीय ऋषियों ने इस तत्त्व को सूर्य-विज्ञान से समझा है। भारतीय चिन्तन की आधुनिक वैज्ञानिक, प्राद्यौगिकी युग में क्या प्रासंगिकता है तथा कितना प्रकाशोन्मुख पदार्थ एवं प्रकाश का चिन्तन रहा है, यह 'रमन-प्रभाव' के परिप्रेक्ष्य में भास्वर हो उठता है। सूर्य-विज्ञान का तात्त्विक विवेचन अगले अनुच्छेदों में प्रसंगानुकूल उपस्थापित होगा। यहाँ सर्वप्रथम 'रमन-प्रभाव' का स्पष्टीकरण समीचीन है।

रमन ने सन् 1921 में पदार्थ पर प्रकाश के प्रभाव की खोज की। इस समय इस खोज के तीन सहयोगी : के. आर. रामनाथन्, रमन और रामनाथन थे। काफी

हद तक खोज में पहुँचा जा चुका था, पर पूर्ण सफलता न मिल सकी। पांच वर्ष बाद उन्होंने पुनः अपने तीन नये सहयोगियों श्री करियमाणिक्यम् श्री निवास, कौर्णन वेंकटेश्वरन् और आशुतोष दे, के साथ कार्य प्रारम्भ कर दिया। सन् 1928 की फरवरी में 'रकन-प्रभाव' की अपूर्व उपलब्धि हुई। इसके सम्बन्ध में जर्मन की एक वैज्ञानिक पत्रिका में पीटर प्रिंगशाइम में शोध विवरण समापन अनुच्छेद में लिखा : 'रमन की खोज एक ऐसी नितान्त नयी घटना है, जिसे 'रमन-प्रभाव' [RAMAN-EFFECT] नाम देना उचित होगा। तभी से यह खोज 'रमन-प्रभाव' से विश्वविख्यात हो गयी। आइन्स्टीन ने इससे प्रभावित होकर सन् 1953 में कहा था "रमन पहले वैज्ञानिक है जिन्होंने सिद्ध किया कि द्रव्य के भीतर प्रकाश के फोटान कणों की ऊर्जा में आंशिक परिवर्तन हो सकता है।"

भौतिकी शास्त्र के क्वैन्टम सिद्धान्त में यह मान्यता है कि प्रकाश किरणें ऊर्जा के फोटान कणों का समूह है। एक रंगी प्रकाश के सभी फोटान निश्चित ऊर्जा के होते हैं। फोटान की ऊर्जा या तरंग दैर्ध्य में परिवर्तन होता है तो प्रकाश के रंग भी परिवर्तित हो जाते हैं। एक रंगी प्रकाश किरण के किसी पदार्थ से टकराने पर तीन स्थितियाँ हो सकती हैं :—

(क) परावर्तित होने वाले फोटान कणों की ऊर्जा में कोई परिवर्तन नहीं होगा।

(ख) या फोटान कण अपनी थोड़ी ऊर्जा उस पदार्थ के अणुओं को प्रदान कर कम ऊर्जा के साथ बिखर जायेगें।

(ग) फोटान कण उस पदार्थ के कुछ अणुओं की ऊर्जा प्राप्त कर अधिक ऊर्जा के साथ बिखरेगा। फोटान कण के परिवर्तन होने पर बिखर जाने वाले प्रकाश के रंग में भी परिवर्तन हो जाता है। इसी रंग परिवर्तन का नाम 'रमन-प्रभाव' [RAMAN-EFFECT] है।

जब कोई भी एक रंगी प्रकाश किसी पदार्थ से टकराता है तो उससे एक अल्पांश (आरम्भिक प्रकाश के दस करोड़वें हिस्से) का रंग बदल जाता है। रमन ने इसी परिघटना की खोज की। स्पेक्ट्रोस्कोपी की सहायता से इन परिवर्तित रंगों को पृथक पहिचाना जा सकता है। "रमन-प्रभाव" से अणु-परमाणुओं की संरचना का परिज्ञान होता है। इसके साथ ही पदार्थ के भीतर अणुओं की दूरियों और उनके आपसी सम्बन्धों को भी जाना जा सकता है। रमन स्पेक्ट्रोस्कोपी से पदार्थ स्थापत्य का बोध होता है। आरम्भ में इन्होंने सूर्य प्रकाश के स्रोत का उपयोग किया। फिर मर्क्यूरी लैम्प के तेज प्रकाश का प्रयोग किया गया। पर लेसर किरण की खोज के बाद रमन स्पेक्ट्रोस्कोपी के लिए एक रंगी प्रकाश स्रोत लेसर किरण प्राप्त हो गयी। लेसर किरणें एकही आवृत्ति अर्थात् एकही विशुद्ध रंग की होती है। सन् 1962 में सर्व प्रथम लेसर किरण प्रयोग से

रमन-स्पेक्ट्रम को प्राप्त किया गया। तब से आज तक उसका उपयोग हो रहा है। नये-नये लेसर स्रोतों को खोजने में भी इससे सहायता मिल रही है।

सूर्य विज्ञान सूर्य रश्मि ज्ञान का अभिव्यंजक हैं। यह रश्मि वर्ण या रंग से अभिहित है। इसी के विभिन्न प्रकार के संयोग-वियोग से अनेक प्रकार के पदार्थों की सत्ता व्यक्त होती है। इसलिए रश्मि पदार्थों की सत्ता की प्रकाशिका है। सूर्य रश्मि के ज्ञान से विभिन्न रश्मियों के परस्पर संगठन का वोध सूर्य विज्ञान है। इसके रहस्य को स्वामी विशुद्धानन्द परमहंस ने कहा है—"सूर्य ही जगत का प्रसविता है। जो पुरुष सूर्य की रश्मि अथवा वर्णमाला को भलीभाँति पहचान गया है और वर्णों को शोधित करके परस्पर मिश्रित करना सीख गया है, वह सहज ही सभी पदार्थों का संघटन या विघटन कर सकता है। वह देखता है कि सभी पदार्थों का मूल वीज इस रश्मि माला के विभिन्न प्रकार के संयोग से ही उत्पन्न होता है। वर्ण भेद से और विभिन्न वर्णो के संयोग भेद से विभिन्न पद उत्पन्न होते हैं, वैसे ही रश्मि भेद और विभिन्न रश्मियों के मिश्रण भेद से जगत के नाना पदार्थ उत्पन्न होते हैं। अवश्य ही यह स्थूल दृष्टि में वीज-सृष्टि का एक रहस्य है। सूक्ष्म दृष्टि में अव्यक्त गर्भ में बीज ही रहता है।·········जो इस योजना को और विनियोजन की प्रणाली को जानते हैं। वे सभी कुछ कर सकते हैं। निर्माण भी कर सकते हैं और संहार भी; परिवर्तन की तो कोई बात ही नहीं।"[1]

स्पष्ट है सृष्टि के अस्तित्व के लिए सूर्य परम तत्त्व है। सूर्य रश्मियाँ संघटन, स्थिति, संहार सबका हेतु है। अतः प्रकृति के रहस्य जानने में सूर्य साधन है—

हिरण्मयेन पात्रेण सत्यस्यापिहितं मुखम्[2]
योऽसावादित्ये पुरुषः सोऽहम्·········

सूर्य से सब जगत उत्पन्न है। उपनिषद कहता है कि प्रसव-धर्मिता के कारण ही सूर्य सविता है। (सवनात् सविता): "पूङ् प्राणिप्रसवे इत्यस्य धातोरेतदरूपम सुनोति सूयते वा उत्पादयति चराचरं जगत स सविता। पु प्रसवैश्वर्ययो :—सर्ववस्तूनां प्रसवः उत्पत्ति स्थानं सर्वैश्वर्यस्य च।" स्पष्ट रूप से सूर्य जगत की उत्पत्ति का हेतु हैं :

सूर्याद् भवन्ति भूतानि सूर्येण पालितानितु
सूर्ये लयं प्राप्नुवन्ति य : सूर्य : सोऽहमेव च।[3]

आचार्य शौनक का वृहद्‌वता में कथन है कि एक मात्र सूर्य से ही भूत, भविष्य और वर्तमान के समस्त स्थावर और जंगम पदार्थ उत्पन्न हैं। उसी में वे लीन हो जाते हैं। यही प्रजापति, सत् और असत् के योनि स्वरूप हैं, यह अक्षर, अव्यय, शाश्वत ब्रह्म हैं। तीन भागों में विभक्त होकर तीन लोकों में वर्तमान है। समस्त देवता इनकी रश्मि में समाविष्ट हैं :

भवद्भूतं भविष्यच्च जङ्गमं स्थावरं च यत् ।
अस्यै के सूर्यमेवैकं प्रभवं लयं प्रविदुः ॥
असतश्च सतश्चैव योनिरेषा प्रजापतिः ।
तदक्षरं चा व्ययं च य च्चैतद् ब्रह्मशाश्वतम् ॥
कृत्वेष हि त्रिधात्मनिमेषु लोकेषु तिष्ठति ।
देवानां यथायथं सर्वान् निवेश्य स्वेषु रश्मिषु ॥[4]

"सूर्य-सिद्धान्त" में सूर्य सब जगत का आदि है। इसीलिए उसे "आदित्य" कहते हैं। समूचा जगत उससे प्रसूत है। अतः वह सूर्य और सविता है। यह तमोमण्डल के पार परम् ज्योतिस्वरूप है।

आदित्यो ह्यादिभूत त्वात् प्रसूत्या सूर्य उच्यते ।
परं ज्योतिः तमः पारे सूर्योऽयं सवितेति च ॥[5]

"छान्दोग्योपनिषद्" में प्रणव या उद्गीथ ही सूर्य है।[6] ये सर्वदा नाद किया करते हैं। प्रणव-सूर्य की दो अवस्थाएँ हैं। प्रथमवस्था उनकी रश्मिमाला चारों ओर विकीर्ण है। दूसरी अवस्था में सभी रश्मियाँ संहृत होकर मध्य विन्दु में विलीन है। यह द्वितीय प्रणव की कैवल्यावस्था या शुद्धावस्था है। प्रथमावस्था सूर्य की सृष्टिमुन्मुख अवस्था है। पाइथागोरस (Pythagoras) के अनुसार सूर्य एक तेजोधारक "लेन्स" (Lens) मात्र है। इसी से होकर आत्म ज्योति का जगत में पतन होता है। प्लेटो (Plato) का कथन है कि ज्योति Kabalist और अन्यान्य तत्त्वदर्शियों के अनुसार परम पदार्थ का प्रथम विकास हैं। इसे ही Sephra Divine Intelligence कहा गया है। ईश्वर ने अपनी रश्मियों से जो तेज प्रज्वलित किया है वही सूर्य है।[7] सूर्य प्रकाश या ताप की प्रभा नहीं है, वल्कि वह एक Focus है, एक Lens मात्र है। इसके प्रभाव से आदिम ज्योति का रश्मि समूह स्थूल (Material) वन जाता है, हमारे सौर जगत में एकत्र हो जाता है और अनेक प्रकार की शक्ति उत्पन्न करता है।[8]

सूर्य विज्ञान से रश्मि विन्यास द्वारा मूल वीज को व्यक्त करके पदार्थ का आरम्भ दिखाया जाता है। सूर्य रश्मियाँ अनन्त हैं। पर मूल प्रभा शुक्ल वर्ण एक है। यही शुक्ल वर्ण लाल, नीला आदि वर्णों के रूप में और पुनः इनके परस्पर मेल से अनेक उपवर्णो में इसका प्रकाशन होता है। शुक्ल वर्ण ही विशुद्ध सत्य है। इस सादे प्रकाश पर अनन्त वैचित्र्य पूर्ण संसार की लीला हो रही है। यहाँ जो कुछ भी दृश्य है, वह मिश्रित है। उसका विश्लेपण करके संघटक शुद्ध तत्त्व को जाना जा सकता है। सूर्य विज्ञान रहस्यमय है। यहाँ पर मात्र उसकी एक क्रिया का उल्लेख किया जा रहा है। "गुलाब" से "कर्पूर" की सृष्टि करनी है। सिद्धान्त है : "सर्वं सर्वात्मक जगत" सबमें सबका भाव है। अतः गुलाब को सूर्य - रश्मि विन्यास द्वारा कर्पूर बनाया जा

सकता है। प्रक्रिया कुछ इस प्रक्रम हो सकती है। मान लें चार रश्मियों 'क', 'म', 'त' 'र' के विनियोग से कर्पूर निर्मित होगे। सर्वप्रथम सत्व शुद्धि करके क्रम से पहले 'क' रश्मिका आधान करेगें इसके वाद क्रमशः 'म', 'त', 'र' का आधान होगा। अन्तिम "र" रश्मि का आधान पाते ही "गुलाव" 'कर्पूर' में बदल जायेगा। अर्थात् गुलाव का पूर्वरूप अव्यक्त हो गया और गुलाव में अव्यक्त कर्पूर रूप रश्मि के निधान से प्रकट हो गया। सूक्ष्म दृष्टि से 'गुलाव' कर्पूर नहीं हुआ, अपितु कर्पूर का जो अव्यक्त भाव उसमें था, वह प्रकट हो गया और गुलाव का प्रकट भाव अव्यक्त। ध्यातव्य है कि चारो रश्मियों को एक साथ डाला नहीं जा सकता। क्योंकि विना क्रम के सृष्टि सम्भव नहीं है। काल ही तो क्रम है। इसलिए क, म, त, र रश्मियों में 'क' के वाद "म" और 'त' के बाद 'र' का ही आधान होगा। ऐसा नहीं होगा कि 'क' के वाद 'र' और 'त' के बाद 'म' करके गुलाव से कर्पूर वना लिया जाय। ऋषियों ने सूक्ष्म दृष्टि से इसकी पहिचान किया था और तत्त्व वोध द्वारा सृष्टि रहस्य को उद्घारित किया था। विज्ञान पदार्थ का पदार्थता तक ही पहुँचता है। इसके परे भी कुछ है जो "सविता" के 'वैश्वानर" और उसके "देवत्व" में समाहित हैं। इसकी पहिचान भारतीय ऋषि प्रज्ञा करती है। सूर्य में देवत्व की प्रतिष्ठा करके उसके पदार्थत्व के स्थान पर चेतनत्व को अनुभव किया गया है और कहा गया है "तत्सवितुःवरेण्यं भर्गोदेवस्य धी महि धीयो नः प्रचोदयात्"। विज्ञान पदार्थ की व्यापक यात्रा करता है। पर पदार्थ और चिन्तन की यात्रा में अनेक भेद है। पदार्थ की सत्ता है। पर उसकी गति नहीं है। चिन्तन सत्ता हीन होने के कारण केवल गति है। चिन्तन की गति न केवल दिशा निरपेक्ष हैं, अपितु काल-निरपेक्ष भी होती है। सृष्टि का सृष्टित्व पदार्थ नहीं है, चेतना है। चेतनत्व चिन्तन से अनुभावित है। इस प्रकार चेतना के स्तर पर "सवितर" या "आदित्य" (तत्सवितुः वरेण्यं) और दैहिक स्तर पर अग्नि की दुहरी यात्रा भारतीय चिन्तन की मुख्य विशेषता ही है। इसीलिए भारतवर्ष में ही मंत्री की मंत्रात्मकता सम्भव हो सकी है।

रमन-प्रभाव [RAMAN-EFFECT] पदार्थ स्थापत्य का अभिव्यंजक है। अणु परमाणुओं की संरचना का परिज्ञान तथा पदार्थ के भीतर अणुओं की दूरियां एवं उसके भीतर उनके आपसी सम्बन्धों की पहिचान 'रमन-प्रभाव' की उपलब्धि है। पदार्थ पर प्रकाश के टकराव की स्थिति जन्मरूप की दिककाल संयुक्त प्रभाव एवं उसके विखराव का क्या स्वरूप है, यह "रमन-प्रभाव" स्पष्ट करता है। रमन ने प्रारम्भ में सूर्य प्रकाश को स्रोत रूप में उपयोग किया था। भारतीय ऋषि कल्प में सूर्य - रश्मियों का सूक्ष्म ज्ञान है। सूर्य रश्मियाँ अनन्त हैं। उनमें सवकी पहिचान असम्भव हैं। पर कुछ की पहिचान कर पदार्थ की सृष्टि की जा सकती है। सूर्य-वैज्ञानिक रश्मि (स्पेक्ट्रम) को पहिचानकर एक पर उसका आरोप करके उससे भिन्न नयी सृष्टि कर सकता है। पदार्थ की सत्ता होने पर प्रकाश रश्मि के टकराव की क्या स्थिति है, इसका प्रत्यभिज्ञान

रमन-प्रभाव करता है। पर पदार्थ को निर्मित सूर्य [illegible] कर सकता है। 'रमन-प्रभाव' से भारतीय सूर्य-विज्ञान और भौतिकी ज्ञान को [illegible] नया आयाम मिला है। इतना निश्चित है कि भारतीय आर्षता को वैज्ञानिक चेतना (Scientific-Temper) की आज भी प्रासंगिकता है।

संदर्भ

1. भारतीय संस्कृति एवं साधना, म. म. पं. गोपीनाथ कविराज पृ. 422
2. मैत्री-उपनिषद्, 6/35
3. सूर्योपनिषद।
4. वृहद्देवता : आचार्य शौनक।
5. सूर्य सिद्धान्त।
6. छान्दोग्योपनिषद।
7. Timacus : द्रष्टव्य।
8. भारतीय संस्कृति एवं साधना : म. म. पं. गोपीनाथ कविराज पृ. 431.

विश्वविद्यालय के उद्देश्य

1. अखिल जगत् की सर्वसाधारण जनता के एवं मुख्यतः हिन्दुओं के लाभार्थ हिन्दू शास्त्र तथा संस्कृत साहित्य की शिक्षा का प्रसार करना, जिससे प्राचीन भारत की संस्कृति और उसके विचार-रत्नों की रक्षा हो सके, तथा प्राचीन भारत की सभ्यता में जो कुछ महान् तथा गौरवपूर्ण था, उसका निदर्शन हो।
2. साधारणतः कला तथा विज्ञान की समस्त शाखाओं में शिक्षा तथा अन्वेषण के कार्य की सर्वतोन्मुखी उन्नति करना।
3. भारतीय घरेलू धन्धों की उन्नति और भारत की द्रव्य-सम्पदा के विकास में सहायक आवश्यक व्यावहारिक ज्ञान से युक्त वैज्ञानिक, तकनीकी तथा व्यावसायिक शिल्प कलादि सम्बन्धी ज्ञान का प्रचार और प्रसार करना।
4. धर्म तथा नीति की शिक्षा का आवश्यक अंग मानकर नवयुवकों में सुन्दर चरित्र का गठन करना।

OBJECTS OF THE UNIVERSITY

1. To promote the study of the Hindu Shastras and of Samskrit literature generally as a means of preserving and popularizing for the benefit of the Hindus in particular and of the world at large in general, the best thought and culture of the Hindus, and all that was good and great in the ancient civilization of India.
2. To promote learning and research generally in Arts and Sciences in all branches.
3. To advance and diffuse such scientific, technical and professional knowledge combined with the nccessary practical training as is best calculated to help in promoting indigenous industries and in developing the material resources of the country; and
4. To promote building up of character in youth by religion and ethics as an integral part of education.

मुद्रक : सीमा प्रेस, ईश्वरगंगी, वाराणसी। फोन : 52092